



Suitability of four main Mediterranean tree crops for their growth in peri-urban agriculture and restoration (Gabes, Tunisia)

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Abstract

In order to increase the knowledge about crop tolerance to air pollutants in the different agroclimatic zones of the world, so that they can be efficiently considered for improving peri-urban agriculture, increasing the success of restoration projects, or enhancing air quality in polluted sites, the suitability of four economical valuable tree crops of the Mediterranean agriculture were studied under field conditions: date palm tree (*Phoenix dactylifera* L.), pomegranate (*Punica granatum* L.), fig tree (*Ficus carica* L.), and olive tree (*Olea europaea* L.). The measurement of biochemical markers such as ascorbic acid content, leaf relative water content, leaf total chlorophyll and leaf extract pH, at two contrasted air quality sites, a polluted site located around Gabes (Tunisia) industrial area and a control site, allowed the assessment of the air pollution tolerance index (APTI) and anticipated performance index (API) for the assayed species. Results showed obvious differences between the evergreen and the caducifolious tree crops assayed. *Phoenix dactylifera* tree (API = 6) was classified as an excellent performer for growing under poor air quality, followed by *Olea europaea* tree (API = 2) which was classified as a moderate performer. Both of trees can be recommended for successful results in peri-urban agriculture and restoration projects of polluted areas in the Mediterranean climate; on the contrary, the suitability of the *Punica granatum* (API = 1) was very poor, but still potentially interesting as a biological indicator of air pollution. Regarding the *Ficus carica* tree (API = 0), this species is not suitable for growing in air-polluted areas.

Keywords Air pollution indicators · API · APTI · Peri-urban agriculture · Green solutions · Restoration projects

Introduction

Due to the continuous growth of industrial activities, atmospheric pollution is becoming a serious global problem. The industrial processes release multiple air pollutants both gaseous and particulate into the atmosphere, causing mixed pollution that inevitably deteriorate air quality and damage the environment (Begun and Harikrishna 2010; Alotaibi et al.

2020). To control air pollution, many methods have been used, but green plants provide the best natural strategy for cleaning the environment. Despite of their important role, vegetation and crops surrounding urban and industrial areas could be affected by air pollutants. Atmospheric gaseous pollutants enter inside the plant mainly through stomatal pores during the gas exchange process of carbon fixation causing harmful effects on plant metabolism and physiology (Koblar et al. 2011; Zouari et al. 2014). The effects of the mixed pollutants at physiological scale frequently derive into visible foliar damage (Liu and Ding 2008), decrease of plant growth (Anjos et al. 2018), and finally negatively affect plant yield parameters (Kozioł and Whatley 2013; Santos et al. 2015). In general, roots are less exposed to the airborne pollutants, compared to the leaves, where pollutants can be absorbed and accumulated massively. Thus, the effects are frequently more intense on aerial parts of the plant (Tiwari et al. 2006; Balasubramanian et al. 2018). Several studies have determined the early impact of air pollution on some biochemical parameters, such as chlorophyll content (Nadgórska-Socha

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et al. 2017), soluble sugars (Prado et al. 2000), ascorbic acid content (AAC) (Hoque et al. 2007), leaf extract pH (Klumpp et al. 2000), and relative water content (RWC) (Kaur and Nagpal. 2017). These biochemical indicators have been considered as early markers for detecting air pollutant's impacts on plants. In this sense, leaf total chlorophyll content (LT chl), AAC, leaf pH, and RWC were considered for building the air pollution tolerance index (APTI) (Shannigrahi et al. 2003). An empirical relationship among these parameters determines the responses of plant capacity to resist air pollution based on early biochemical markers. Originally formulated by Singh and Rao (1983) and Singh et al. (1991), APTI was successfully applied on studies around industrial areas and pollution mitigation at roadside sites and around industries and has been considered as the best index to identify the plant responses against the air pollution (Gholami et al. 2016; Nadgórska-Socha et al. 2017) and to evaluate plant susceptibility under field conditions (Ogunkunle et al. 2015).

Ascorbic acid content was considered in APTI due to its important role within the plant cellular antioxidant system. The reducing power of the AAC depends of the pH values, where the less protection effect was obtained with lower pH. Generally, high pH values in leaf extract indicate more tolerance to pollutants (Agbaire and Esiefarienrhe 2009). For APTI, both parameters (AAC and leaf pH) are related to the potential capacity of the plant to block the penetration of pollutants through plant tissues. On the other hand, RWC in the index is related to the healthy state of the cell membrane to maintain its permeability and functionality under polluted ambient air (Seyyednejad et al. 2017); meanwhile, chlorophyll content has been considered as a general indicator of plant tolerance (Rai and Panda 2014) related with plant productivity in terms of photosynthetic activity, growth, and biomass development (Raza and Murthy 1988; Girish et al. 2017). All the parameters considered within the APTI play an important role in their value; thus, alterations in any of them affect directly the index.

APTI permits to identify and classify plant species for three levels (tolerant, intermediate, or sensitive) to air pollution (Singh et al. 1991; Liu and Ding 2008; Gholami et al. 2016). This classification generates several direct applications: the sensitive species can be considered as bioindicators of air pollution, while tolerant species can be proposed for green solutions in polluted areas (Prajapati and Tripathi 2008; Kousar et al. 2014; Maity et al. 2017).

The original APTI was modified by Govindaraju et al. (2012) and combined with some socioeconomic and biological characters to evaluate the anticipated performance index (API). This modified index included more parameters such as plant height, type of plant, canopy, and luminal structure, which add more criteria for a better indicator of the species capability for removing air pollutants and species performance to clean up polluted environments (Agbaire and Esiefarienrhe

2009; Pandey et al. 2015). API species classification ranged from “not recommended” to “best” categories in the framework of restoration projects or green urban infrastructures.

International forums like the Environmental Program of the United Nations is joining science communities to launch major new pushes on using more efficient green solutions to sustainable development (Environment Program UN 2019). To follow this command, it is crucial to generate knowledge about plant species tolerance to air pollutants for the different agroclimatic zones of the world. Therefore, they can be efficiently be used in cleaning air-polluted areas and in restoring projects.

Tunisia, the fifth world producer of phosphates, is home for several factories specialized in phosphate process and transform. It is evident that the industrial phosphate complex is the main source of air pollutants containing hydrogen fluoride (HF), sulfur dioxide (SO₂), and nitrogen oxides (NO_x). Around 13 million tons of phosphates are extracted annually in Tunisia, of which 80% is treated in Gabes and Sfax regions. Ben Abdallah et al. (2006) found that around the phosphate fertilizer industry, fluoride highly leads the emissions, being the main concern as a phytotoxic air pollutant. Due to this, the Gulf of Gabes is listed among the “pollution hot spots” of the Mediterranean under the Strategic Action Program (SAP) of the United Nations Environment (UNEP). On the same line, the World Bank and the Facility for Euro-Mediterranean Investment and Partnership (FEMIP) classified the city of Gabes as one of the most polluted areas in the Mediterranean basin. However, only recently, the study of the air pollutants' effects on tree crops and vegetation surrounding the area has started (Elloumi et al. 2016; Ben Amor et al. 2018).

Around Gabes factories extends the only coastal oasis in the Mediterranean basin, a very valuable traditional agroecosystem from both ecological and economical points of view. Characteristic Mediterranean tree crops like date palm (*Phoenix dactylifera* L.) and olive tree (*Olea europaea* L.) grown in the zone are exposed chronically to the continuous emissions of air pollutants from the phosphate factory. Because of their high production, both species are the most important tree crops for the agronomic sector in the arid regions in the south of Tunisia, which is key for the Tunisia's position as the first dates exporter: 24% of the global trade in dates and the second largest exporter of olive with 75% of its production during the period of 2008-2012 (ONH 2013). Other important species of consumable value in the area are fig (*Ficus carica* L.) and pomegranate tree (*Punica granatum* L.). In fact, total fig production represents 3% of world production (FAO, 2015). In addition, Gabes is considered as the first Tunisian governorate in terms of pomegranate production and surface (Mansour et al. 2011) with dominance of “Gabsi” variety, which constitutes 75,000 tons of the total national production.

Considering all these facts, the aims of the present work are (i) to assess some biochemical changes induced on the tree crops (date palm, olive, fig, and pomegranate trees) growing under field conditions around the phosphate industrial complex of Gabes, (ii) to evaluate the susceptibility levels of these species through a field study of the APTI/API, and (iii) to assess the capacity of these species as efficient green solutions in restoration projects in urban and peri-urban Mediterranean regions.

Materials and methods

Area description

The present work was carried in the fields close to the industrial area of Gabes (33° 88' 97.05" N 10° 09' 76.80" E), located in the southern side of the Gulf of Gabes in the Mediterranean Sea (Fig. 1). Gabes presents a characteristic of arid climate with a daily temperature range between 16 and 33 °C and an annual precipitation less than 100 mm. The main wind direction comes from the northeast toward the southwest (Meteorological Network of Gabes City). The study area presents numerous sources of air pollution, mainly chemical industries. The industrial park includes 5 units of acid production and 6 acid sulfuric units. The main pollutants generated by the process of production and treatments are SO₂, NO_x, NH₃, fluoride, and some heavy metals such as Pb and Cd (Elloumi et al. 2017). Leaf fluoride content measured on *Phoenix dactylifera* trees planted around the industrial area of Gabes was high, around 96 µg/g DW (Ben Amor et al. 2018), and the *Punica granatum* accumulation was about

twofold higher, with the value of 150 µg/g DW (Elloumi et al. 2016). In addition to gaseous, air particulate matter (PM), containing Cd, Pb, Zn, Cu, and Fe, was released by the industrial park (Taieb and Ben Brahim 2014). Some studies indicate airborne PM₁₀ values around Gabes area within the range 1750–3436 T/year and 80–329 µg/m/day (ANPE 2018). About 95% of PM₁₀ including heavy metals was originated from the chemical industries of the Gabes area (Taieb and Ben Brahim 2014). Around the industrial area, leaf deposition of particulate pollutants and visible injury were easily seen (Fig. 2).

Sampling sites and plant selection

Four typical Mediterranean tree species—date palm (*Phoenix dactylifera* L.), olive (*Olea europaea* L.), pomegranate (*Punica granatum* L.), and fig (*Ficus carica* L.)—were considered for the study. Two experimental sampling stations were considered: the polluted site (PS) (33° 90' 43.43" N, 10° 09' 02.14" E) located 1 km from the factory following wind dominant direction and the control site (CS) (33° 66' 11.09" N, 10° 35' 50.30" E) located 37 km far away from the factory (Fig. 1). Within each site, five trees per species were sampled; trees were randomly selected to represent the general age and size of the species in the orchards. A 10-g pool of fresh leaves per tree was collected from branches oriented towards industrial factory wind direction, which is also the main wind in the area. Samples were preserved through refrigeration in the field and then transported to the lab where they were prepared and frozen until biochemical analysis. For all analysis, each sample was replicated five times. Plants were sampled in spring 2018; this period was chosen to match

Fig. 1 Maps of Tunisia localization and location of study area (Gabes governorate) and the sampling sites around the industrial park. PS, polluted site; CS, control site

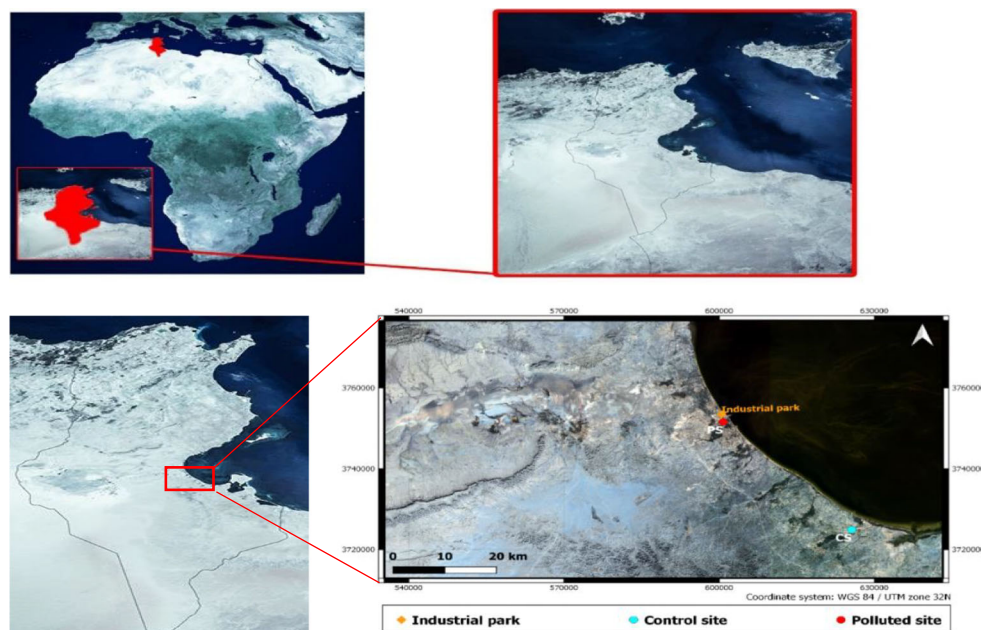
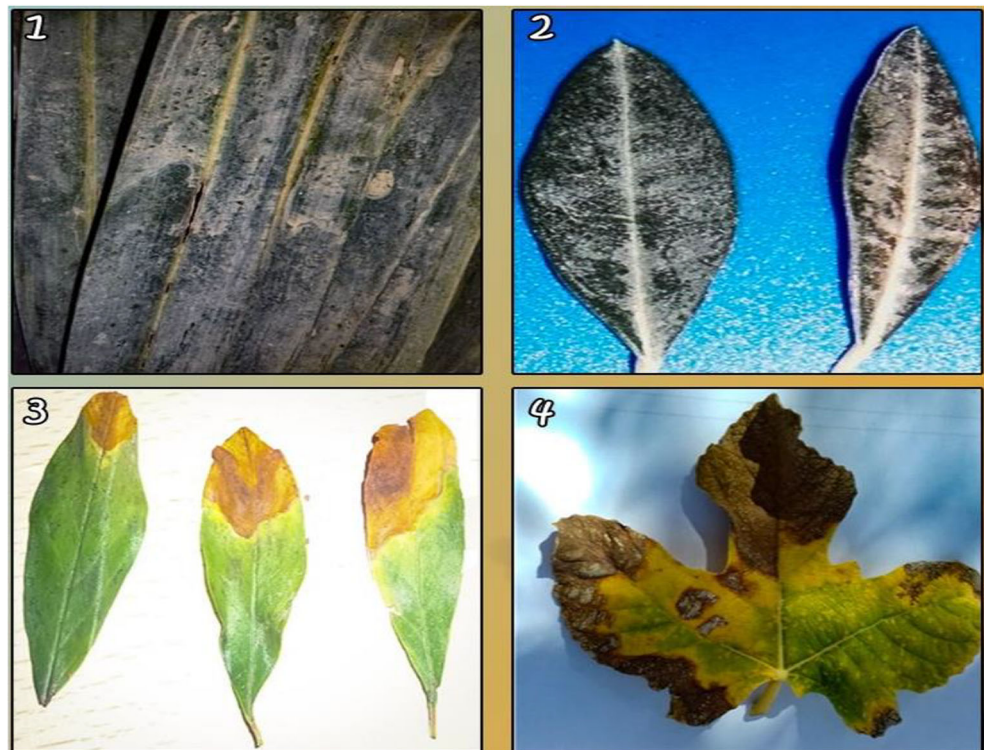


Fig. 2 Particulate depositions in leaves of evergreen species (1, 2) and visual symptoms of air pollution in leaves of deciduous species (3, 4)



with high plant physiological activity and the flowering season.

Methods for biochemical analysis

Total chlorophyll content

The concentration of total chlorophyll was determined according to the method of Lichtenthaler and Wellburn (1983) and previously described by Skrynetska et al. (2018): 0.5 g of fresh leaves were ground in 5 mL of 80% acetone solution. After filtration, the extraction was adjusted to 15 mL with 80% acetone, and the content of chlorophyll pigments was determined spectrophotometrically.

Relative water content

RWC was determined and calculated according to the method described by Liu and Ding (2008):

$$RWC (\%) = \frac{\text{Fresh weight} - \text{Dry weight}}{\text{Turgid weight} - \text{Dry weight}} \times 100$$

Fresh weight was measured in the lab immediately after the field sampling; for fully turgid weight, excised leaves were submerged in water for 24 h; for dry weight, leaves were desiccated in the stove for 48h at 60 °C.

Ascorbic acid content

The AAC content of leaves was determined using spectrophotometric method. Briefly, 1 g of fresh leaves was extracted with 5 mL of 10% trichloroacetic acid (TCA). The mixture was centrifuged for 20 min at 1235 rpm. After that, 1 mL of 6 mM 2,4-dinitrophenylhydrazine-thiourea-CuSO₄ (DTC) was added to 0.5 mL of the extract. The solution obtained was incubated at 37 °C for 3 h. Then, 0.75 mL of ice-cold 65% H₂SO₄ was added. The absorbance was read at 520 nm with a UV/Vis spectrophotometer (Perkin Elmer, Norwalk, USA). To calculate the AAC concentration, a standard curve was prepared with ascorbic acid standard (Ali et al. 2014).

Leaf extract pH

A method described by Agbaire and Esiefarienrhe (2009) was used to determine the pH of leaf extract; 100 mg of fresh leaves was homogenized in 10 mL de-ionized water. After filtration, the pH was determined with a pH meter.

Determination of air pollution tolerance index

The APTI for the selected trees was calculated following the equation proposed by Singh et al. (1991): $APTI = [A (T + P) + R] / 10$.

where A = ascorbic acid content (mg/g), T = total chlorophyll (mg/g), P = pH of the leaf extract, R = relative water content of leaf (%).

Sensitivity classification based on APTI followed Padmavathi et al. (2013): sensitive for ATPI range 1–11, intermediate for ATPI range 12–16, and tolerant for ATPI higher than 17.

Determination of anticipated performance index

Following Govindaraju et al. (2012), results of APTI were combined with some socioeconomic and biological characters, such as canopy structure, plant habitat, plant type, and laminar structure of the canopy to determine API (Table 1). All the factors included in the index affect plant performance, including APTI. Different grades (+ or –) are allotted to each studied species. Based on their grades, each species will be scored and API will be calculated (Table 2). Species with higher API are the highest ones suitable for the green belt development.

Statistical analysis

Data were expressed as mean \pm standard error (mean \pm SE). Significant differences between species in the two sites were determined by two-way analysis of variance (ANOVA), followed by Duncan's test to correct for multiple comparisons

Table 2 Anticipated performance index (API) score assessment (Govindaraju et al. 2012)

Grade	Score (%)	Assessment category
0	< 30	No recommended
1	31–40	Very poor
2	41–50	Poor
3	51–60	Moderate
4	61–70	Good
5	71–80	Very good
6	81–90	Excellent
7	91–100	Best

with acceptable statistical level of significance set to $p < 0.05$ using IBM SPSS Statistics 25. PCA analysis were carried out with XLSTAT version 2014.

Results

Biochemical parameters

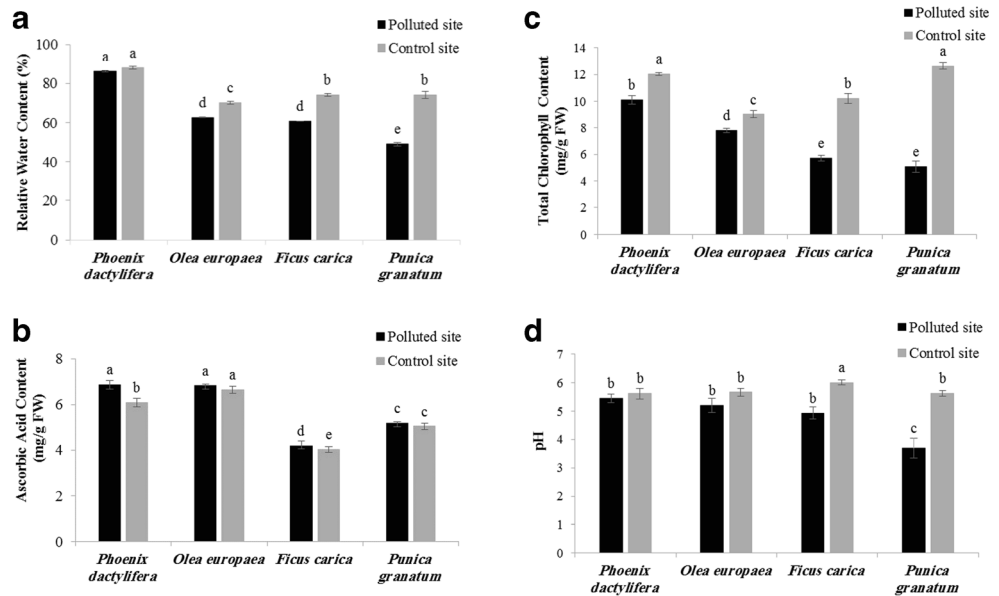
Statistically, a significant difference ($p < 0.05$) was found among species, in terms of leaf water content (Fig. 3(A), Table 6). The highest RWC value was registered for

Table 1 Allotment of gradation to selected plant species (Govindaraju et al. 2012)

Grading character		Pattern of assessment	Grade	
Tolerance	APTI	9.0–12.0	+	
		12.1–15.0	++	
		15.1–18.0	+++	
		18.1–21.0	++++	
		21.1–24.0	+++++	
Biological and socioeconomic	Plant height	Small	–	
		Medium	+	
		Large	++	
	Canopy structure	Sparse-irregular-globular	–	
		Spreading crown/open/semi-dense	+	
		Spreading dense	++	
	Type of plant	Deciduous	–	
		Evergreen	+	
	Laminar structure	Size	Small	–
			Medium	+
Large			++	
Texture		Smooth	–	
		Coriaceous	+	
Hardness		Delineate	–	
		Hardy	+	
Socioeconomic value		Less than 3 uses	–	
		3 or more uses	+	
		More than 5 uses	++	

Total plus that plant can obtained = 16

Fig. 3 Variation in relative water content (A), ascorbic acid content (B), total chlorophyll content (C), and pH content (D) of plants studied in polluted and control sites. The errors bars indicate mean \pm SE ($n = 5$). Different letters (a–c) indicate significant differences ($p < 0.05$) between species and site according to Duncan's test



Phoenix dactylifera (88%, mean value for the control site), while the lowest was shown for *Punica granatum* (74.07%).

When comparing the two sites, the RWC were much higher in the CS than in the PS, close to the complex factory. This reduction was significant for *Olea europaea*, *Punica granatum*, and *Ficus carica* tree, whereas no significant difference was found for *Phoenix dactylifera* species. The loss does not exceed 2%. The different RWC behavior was remarkable between perennial and deciduous tree crops in the PS. Under stress of pollution, the RWC of *Punica granatum* and *Ficus carica* was 34 and 18% respectively and, in contrast, less than 2% for *Phoenix dactylifera* and 11% for *Olea europaea*.

The AAC content varied from 4.2 to 7 mg/g FW (Fig. 3(B), Table 6). The highest AAC was found in *Phoenix dactylifera* and *Olea europaea* (6.84 mg/g FW). However, the lowest was recorded for *Ficus carica* (4.2 mg/g FW) followed by *Punica granatum* (5.18 mg/g FW). All the studied species collected from the PS were showed a high AAC compared with the control. Interestingly, AAC was increased for *Phoenix dactylifera* in the PS to reach 33% compared to the CS; meanwhile, a slight increase was measured in *Olea europaea* (5%), *Punica granatum* (7%), and *Ficus carica* (3%) (Fig. 3(B)).

Regarding the total chlorophyll content, this parameter varied among the species and the sites (Fig. 3(C), Table 6). *Phoenix dactylifera* presented the highest foliar chlorophyll levels with a mean value of 11.06 mg/g FW. Considering the variation between sites, chlorophyll content on the PS significantly presented a lower value than the control for all the species assayed. The total chlorophyll content in the PS varied between 5.07 and 10.08 mg/g FW. However, it ranged between 9.02 and 12.64 mg/g FW, in the CS. All species showed a significant decrease in the foliar chlorophyll content in the PS compared with the CS, but the caducifolia species

suffered more intensively the impact of the pollution presenting 60 and 44% decrease in chlorophyll content for *Punica granatum* and *Ficus carica* respectively; however, the reduction observed on the perennial tree crops was 16% for *Phoenix dactylifera* and 14% for *Olea europaea*.

Leaf extract pH showed significant differences among the studied species (Fig. 3(D), Table 6). Similarly, to AAC, the maximum means value was observed in *Phoenix dactylifera* (5.53), whereas the minimum was found in *Punica granatum* (4.66) (Fig. 3(D)). At the CS, the leaf extract pH presented a wide range (from 5.6 to 6) compared with the more restricted range found at the PS (3.6 to 5.45, mean values across species) (Fig. 3(D)). Differences in this parameter between sites were significant for *Phoenix dactylifera*, which presented an increase of 4% in the leaf pH value compared with the CS. Thus, differences between sites for *Punica granatum* and *Ficus carica* were not significant (Fig. 3(D), Table 6). *Olea europaea* samples collected from both sites presented the same value of pH (pH = 5.73). Considering vegetation types, evergreen species presented higher values in PS; in contrast, deciduous species showed higher pH value at CS.

Determination of APTI

The calculated values of APTI for all the tree crops are presented in Table 3. The studied species presented different APTI accordingly with the different responses of the parameters included in the index. The higher APTI value was recorded for *Phoenix dactylifera* (19.3), followed by *Olea europaea* (15.1), *Ficus carica* (10.6), and *Punica granatum* (9.5). *Phoenix dactylifera*, characterized by not only the highest RWC and total chlorophyll content but also the highest response to the pollution by means of AAC and pH increments,

Table 3 APTI of selected plant species in different sites

Plant species	APTI CS	APTI PS	Tolerance level
<i>Phoenix dactylifera</i> L.	19.37 ± 0.36 ^a	19.3 ± 0.46 ^a	Tolerant
<i>Olea europaea</i> L.	16.59 ± 0.28 ^b	15.1 ± 0.14 ^b	Intermediate
<i>Ficus carica</i> L.	14.35 ± 0.22 ^b	11 ± 0.28 ^d	Sensitive
<i>Punica granatum</i> L.	15.83 ± 0.35 ^c	9.5 ± 0.29 ^c	Sensitive

Values represent the mean of 5 replications per treatment ± SE. Different letters indicate significant differences among treatments ($p < 0.05$)

PS polluted site, CS control site

presented the highest tolerance index; thus, it was classified as a high-tolerant species to air pollution. *Olea europaea* was considered as moderate-tolerant species; on the other hand, *Punica granatum* and *Ficus carica* were classified as sensitive tree crops to air pollution. They present the highest loss of water, total chlorophyll concentration, and also the highest level of pH.

Assessment of API

Tables 4 and 5 show API values for the different assayed species. API varied from not recommended to excellent scale. *Phoenix dactylifera* presented the highest value of this index, API = 6. Thus, it was cataloged as the best suitable for tolerate air pollution followed by *Olea europaea* (API = 2), the moderate performer for living under polluted ambient. Next, *Punica granatum* (API = 1), is classified as a very poor species for pollution tolerance, and *Ficus carica* (API = 0) is not a recommended species for poor air quality.

Table 4 Assessment of tree species based on their APTI values and some biological and socioeconomic characters

		Plant species			
		<i>Punica granatum</i> L.	<i>Phoenix dactylifera</i> L.	<i>Olea europaea</i> L.	<i>Ficus carica</i> L.
APTI		+	+++	++	+
Tree habit		+	++	+	+
Canopy structure		+	++	+	–
Type of plant		–	+	+	–
Laminar	Texture	–	+	+	–
	Size	+	++	+	+
Economic importance		+	+	+	+
Hardness		–	+	+	–
Grade	Total plus	5	13	9	4
allotted	Score (%)	31.25	81.25	56.25	25

Principal component analysis

Multivariate analysis was applied to all studied datasets. The principal component analysis (PCA) scatter plot clearly showed the relationships among species in different sites and measured parameters (Fig. 4). A total of 84.24% of the whole variability was explained by the relationship between PC1 and PC2 (61.55 and 22.68%, respectively). The first PC (PC1), which is the most important component, was positively related to ascorbic acid content, APTI, total chlorophyll content, RWC, and pH. Accordingly, a positive correlation was observed between species in different sites (*Phoenix dactylifera* control, *Phoenix dactylifera* polluted, and *Olea europaea* control) and APTI. The second PC (PC2), was negatively related to *Ficus carica* polluted and *Punica granatum* polluted.

Discussion

Plants naturally develop multitude responses to air pollution. These responses vary differently with plant species and the ecological conditions of the study area. In the present study, both selected sites have similar ecological, climatic, and pedo-geochemical characteristics, and their coastal oases are at the same distance from the sea; differences between them result from their different air quality.

APTI was calculated based on the variation of the total chlorophyll content, RWC, AAC, and pH. Chlorophyll content is an indicator of photosynthetic activity. Its degradation was used as a typical biomarker for assessing pollution stress (Achakzai et al. 2017).

Generally, it is known that the variation of leaf total chlorophyll varies with plant tolerance and sensitivity (Chandawat et al. 2011). According to Rai and Panda (2014), the most sensitive plant is one with a low concentration of chlorophyll content. This is the case of *Punica granatum* and *Ficus carica*. In fact, as the result of total chlorophyll reduction, *Punica granatum* and *Ficus carica* growing around the industrial area of Gabes showed clearly the appearance of necrosis and chlorosis. On the contrary, *Phoenix dactylifera* and *Olea europaea* presented the highest levels of total chlorophyll and the lowest percentage of the chlorophyll reduction between the control and the polluted sites, which can explain their tolerance to air pollution. In accordance with previous results, maintenance of higher levels of foliar chlorophyll promotes resistance and tolerance of plants to airborne pollutants (Shannigrahi et al. 2003; Jyothi and Jaya 2010; Rai and Panda 2014).

The present study showed lower RWC for all species collected from the polluted site compared to the control site. The reduction of RWC under air pollution was reported in previous assays. Following the increment of air pollutants, Bakiyaraj and Ayyappan (2014) showed cell permeability

Table 5 Assessment of tree species based on their API

	Plant species			
	<i>Punica granatum</i> L.	<i>Phoenix dactylifera</i> L.	<i>Olea europaea</i> L.	<i>Ficus carica</i> L.
Total (+)	5	13	9	4
Percentage	30	81.25	56.25	25
Values of API	1	6	2	0
Assessment	Poor	Excellent	Moderate	Not recommended

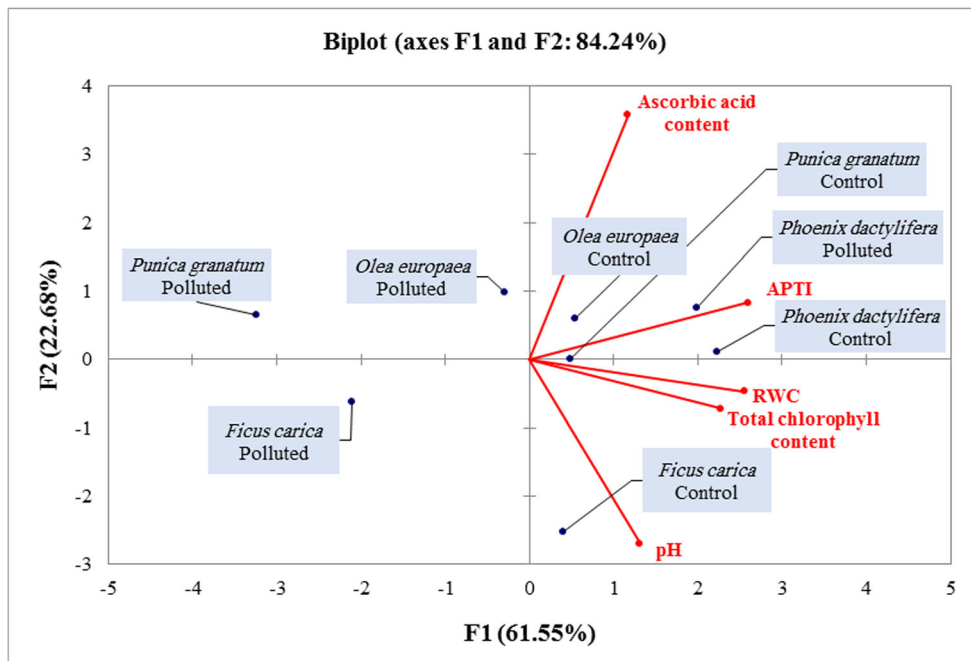
increases, which caused diminution of water content and dissolved nutrients. Relative leaf water content has been associated with protoplasmic cell permeability, so that early senescence follows after water loss and dissolution of nutrients (Agrawal and Tiwari 1997). On the other hand, under stress conditions, such as exposure to air pollution, high RWC can regulate the physiological balance (Tsega and Devi-Prasad 2014; Seyyednejad et al. 2017) and make plants potentially more tolerant to the pollutants (Singh et al. 1991). Verma (2003) indicated how the maintenance of RWC determined the tolerance of the plants to the stress pollution. This can be the case for *Phoenix dactylifera* which presented higher RWC and more importantly preserved a high RWC value under polluted atmospheres. This characteristic might be an important advantage, making *Phoenix dactylifera* a tolerant tree crop to industrial air pollution.

Ascorbic acid (AA) plays an important role in photosynthetic carbon fixation, limiting the oxidative stress during the photosynthetic process; their levels are usually closely related with the total plant chlorophyll content (Conklin 2001). At cellular level, air pollution causes significant production of

reactive oxygen species (ROS), affecting the leaf total chlorophyll concentration (Apel and Hirt 2004). To defend against oxidative damage caused by pollutants, plants usually react by increasing AA concentrations in order to protect thylakoid membrane (Cheng et al. 2007; Subramani and Devaanandan 2015). AA can efficiently protect the chloroplast against the accumulation of H₂O₂, OH⁻, and O₂ caused by the plant exposure to the atmospheric pollution (Chauhan 2010). Accordingly, in the present study, higher AA contents were always found in the polluted area for all the species considered. This increase indicates that all the species responded by activating defense mechanism against oxidative stress. The higher AA concentration recorded in *Phoenix dactylifera* and *Olea europaea* tree crops provides them the highest tolerance level against the industrial pollution around Gabes City. However, the low AA concentrations found in *Punica granatum* and *Ficus carica* suggest their sensitive nature to atmospheric pollution, in agreement with a previous work reported by Chandawat et al. (2011).

pH is also considered as an indicator of plant air pollution sensitivity that can identify the acidic or alkaline nature of the

Fig. 4 Principal component analysis (PCA) to elucidate the relationships between parameters and species cultivated in different studied sites



pollutant (Singh and Rao 1983). In the present study, pH values were lower than 7, pointing towards the presence of acidic pollutants. In fact, Swami et al. (2004) demonstrated that when gaseous air pollutants, such as SO₂ and NO₂ diffuse in the cell sap, they turn in acidic radicals. Frequently, an increment of tissue pH has been related with an improvement of plant tolerance to air pollutants (Agbaire and Esiefarienrhe 2009). As a general consideration, species with pH around 7 or higher could be potentially more tolerant species compared with species with lower pH values (Govindaraju et al. 2012; Abed Esfahani et al. 2013). In agreement with this hypothesis, our results showed that *Punica granatum*, one of the most sensitive of the species assayed, presented the lowest pH values (Table 6).

The variation of some analyzed biochemical parameters will result in the variation of the air pollution tolerance index. Based on the APTI, *Phoenix dactylifera* showed the highest tolerance response to the atmospheric industrial pollution. *Olea europaea* is classified as intermediate tolerant; meanwhile, *Ficus carica* and *Punica granatum* were classified as sensitive species. Thus, the evergreen trees were classified as more tolerant than the deciduous trees. Previous research estimated the classification of some tree species around the industrial area of Gabes and found similar results: Elloumi et al. (2016) classified *Punica granatum* growing around the industrial complexes as sensitive species based on leaf visual damages. Ben Amor et al. (2018) classified *Phoenix dactylifera* as tolerant species based on the absence of leaf damage.

It is interesting to note that despite its continuous exposure to the air pollutants through the seasons, the evergreen species are more tolerant than the deciduous species. Tolerance might be related with plant height and some leaf characters such as size, age, surface area, inclination of leaves, structure, and hardness (Wang et al. 2011). The evergreen species are characterized by their sclerophyllous leaf structures. Leaflets of *Phoenix dactylifera* and leaves of *Olea europaea* are harder than leaves of *Punica granatum* and *Ficus carica*. In addition, the leaves of *Olea europaea* are smaller than pomegranate and fig leaves; the small size of leaves can minimize the contact surface with air pollutants and consequently minimize the leaf atmospheric pollutant concentration. Overall, these findings are in accordance with the results obtained by Elloumi et al. (2016) and Ben Amor et al. (2018) who found that leaf fluoride content

is higher in deciduous trees than in evergreen trees. Also, tolerance of evergreen trees may be related with stomatal architecture, closure, and mineral composition of leaves. High leaf calcium content found in *Phoenix dactylifera* plays an important role to reducing air pollutants. Future studies on element content weighted by leaf area index (LAI) will help in determining the mechanisms of the evergreen tolerance.

With the steady growth of industrialization in southern and eastern Mediterranean countries, the determination of API for the most extended natural and tree crops of the Mediterranean basin is fundamental in order to select tolerant species for plant restoration projects and nature solutions around urban and industrial areas. Planting green vegetation around industrial area is an environmentally sustainable and cost-effective technique for reducing atmospheric emissions, which also beautifies the landscape (Bharti et al. 2018). Recently, this strategy is done in different countries in the world like India (Roy et al. 2020), Nigeria (Ogunkunle et al. 2015; Ogbonna et al. 2019), and Saudi Arabia (Alotaibi et al. 2020). According to Tsega and Devi-Prasad (2014), trees with higher values of API are recommended in the program of green development. The highest APTI, evergreen leaves and dense canopy make *Phoenix dactylifera* as an excellent species to combat atmospheric pollution compared to the other tree crops studied. *Phoenix dactylifera* is a natural species in the area and the principal species grown in oases because of their economic importance. Thus, currently, this species has priority for plantation program to restore the polluted area of Gabes. The results of the present study support the use of this species in restoration areas; it can tolerate the effects of air pollution and can improve air quality for healthy environments. However, no information is available about the quality of their fruits exposed to industrial air pollution. *Olea europaea* is anticipated to be moderate performers and also recommended as an option for plantation in restoration projects in the Mediterranean area. Both evergreen tree crops can play an important role in improving the landscape around the industrial Mediterranean areas considering also other criteria: long-lived trees to reduce the impact of pollutants in the long term, adapted to arid climate—drought stress, high temperature, and low maintenance.

The sensitive species, *Punica granatum* and *Ficus carica*, are anticipated as very poor and not recommended,

Table 6 Analysis of variance of studied parameters between zones and species and their interaction (zones × species)

ANOVA	pH	RWC	Total chlorophyll	Ascorbic acid	APTI
Zones	***	***	***	**	***
Species	***	***	***	***	***
Zones × species	***	***	***	ns	***
Error	0.220	3.917	0.402	0.123	0.500

Significant at * $p < 0.05$, ** $p < 0.01$, and *** $p < 0.001$, respectively

ns non-significant

respectively, for plantation in polluted areas. However, they can be considered as biomonitors of air pollution instead.

Conclusion

The results of present study showed that studied trees respond differently to air pollution. The evergreen species, *Phoenix dactylifera* and *Olea europaea*, maintained the highest values of chlorophyll content and RWC in the polluted site compared with the control, accordingly with their higher levels of the cellular antioxidant AA, being more tolerant to industrial pollution. However, the deciduous species *Punica granatum* and *Ficus carica* reduced their pigment content and RWC in the polluted area, being more sensitive to industrial pollution. Similar trend was observed in their APTI and API. Therefore, *Phoenix dactylifera* and *Olea europaea* which have higher APTI and API are suitable for industrial, urban restoration and for improving air quality in Mediterranean polluted areas. However, the sensitive species, *Punica granatum* and *Ficus carica*, can be used for biomonitoring industrial air pollution in the Mediterranean basin.

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Data availability All data generated during this research process are included in this article.

Compliance with ethical standards

Conflict of interests The authors declare that they have no conflicts of interest.

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