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Evaluating the Potential Use of Four Tree Species in the Greenbelts to Mitigate the Cement Air Pollution in Egypt

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AIR pollution due to industrial emissions is one of the environmental problems in the world. It has negative effects on the environment and the health of living organisms. Tree species can improve the air quality and aesthetic value of the landscape. They are affected by different air pollutants and show varying levels of tolerance and sensitivity when growing as green belts around cement factories. The present study aimed at evaluating the potential use of four tree species (*Eucalyptus camaldulensis*, *Casaurina equisetifolia*, *Conocarpus lancifolius*, *Ficus benjamina*) growing in the green belt of 21 cement factories in Egypt to mitigate air pollution through assessing their air pollution tolerance index (APTI) and anticipated performance index (API), compared with two reference sites. Fresh fully expanded leaves were collected from the selected species at the same time for laboratory measurements of leaf relative water content (RWC), ascorbic acid (AA), total chlorophyll (TCH), and leaf extract pH to calculate the APTI and API. The results showed that *E. camaldulensis* was anticipated as an excellent performer, *C. equisetifolia* and *C. lancifolius* as very good performers, while *F. benjamina* was anticipated as a good performer. The values of API for the target species indicated their tolerance to cement pollution. It is recommended that the target species be planted extensively in the green belts of cement factories and other urban industrial areas to mitigate cement air pollution.

Keywords: Air pollution, Air pollution tolerance index, Anticipated performance index, Cement factories, Green belts, Trees.

Introduction

The rapid growth of industries causes increasing of air pollution in urban areas and is considered the main problem of urban cities (Hamraz et al., 2014). Residential areas in developing countries are sensitive receptors for air pollution (Zhou et al., 2020.). Vehicular exhaust, construction work, and dirty industries such as cement, ceramic, petrochemicals are considered the main reasons for air pollution in urban communities (Ajibade et al., 2021). Stack emissions, open burning, and mobile sources like trucks have dramatically induced in industrial areas (Anake et al., 2016).

Air pollution is considered a major risk for life and is responsible for 11% of deaths annually (WHO, 2016). The monitoring of air pollutants and particulate matter is done by using mobile and stationary stations. However, the number of monitoring stations is not enough, and consequently, the monitoring data do not represent the whole area (Kumar et al., 2015). While this monitoring process is expensive, using trees for air quality monitoring in urban areas is cheap (Mukherjee & Agrawal, 2015; Youssef, 2020). The cement industry is a high-energy, high-carbon process. As a result, they contribute significantly to global anthropogenic CO_2 emissions. With 900kg CO_2 released each production tonne of cement, the cement industry has long been one of the largest CO_2 emitters (Bakhtyar et al., 2017). Globally, cement as a product is the second

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material consumed after water. The cement industry in Egypt exponentially increased in the number of factories and production capacity. The annual production of cement in Egypt is about 55 million tons/year (i.e., about 1.5% of global cement production) (Hussien, 2015). The cement industry is classified as the second source of air pollution after the petroleum industry in Egypt (Salman, 2017).

Sorting trees into tolerant and sensitive species is a fundamental task. Sensitive trees are used as bio-indicator, while the tolerant species could be used as a reservoir for the pollutants in an industrial area (Kuddus et al., 2011). Trees have a clear relationship with ambient air and variation in the atmospheric condition parameters could directly alter the physiology and biochemistry of the trees. Vegetation acts as a reservoir for air pollutants and decreases pollution concentration in the atmosphere (Hamraz et al., 2014). Trees play a major natural role in improving air quality by exchanging gases as they act as a sink for air pollutants, especially carbon dioxides. Trees according to their sensitivity level, can absorb, accumulate, store, and integrate pollutants into their systems. Plants show visible damages and changes in their physiological parameters, which are used to define the air pollution tolerance index (APTI) for plants (Khureshi, 2013). Urban greenery can decrease pollution concentration by accumulating pollutants in its leaves (Aboelkassem et al., 2020). However, pollution is man-made stress for trees (Fusaro et al., 2019), and certain compounds can give a negative impact on plant growth, pigment concentration, and photosynthetic levels (Leghari et al., 2014; Bharti et al., 2018).

Air Pollution Tolerance Index (APTI) refers to the capability of tree species to measure the impacts of air pollutants (Girish et al., 2017). The APTI estimates the impact of pollutants on plants based on biochemical indicators. Tolerant tree species have high APTI values, while sensitive tree species which could be used as bioindicators for air pollution have low APTI values (Bharti et al., 2018). The calculation of APTI depends on some biochemical variables that are negatively impacted by air pollutants such as ascorbic acid content, total chlorophyll, relative water content, and pH of leaf extract (Karmakar et al., 2021). For example, the decrease in chlorophyll content can be increased by SO_2 emission and particulate deposit on the leaf area (Pathak et al., 2015; Molnár et al., 2018). Ascorbic acid as an antioxidant plays an important role in defending against oxidative damage and it has a crucial role in the synthesis of cell walls (Gupta et al., 2016; Nadgórska-Socha et al., 2017; Girish et al., 2017; Sahu et al., 2020). The photosynthetic efficiency of plants is governed by the pH of their leaves, where the acidity of pollutants reduces the leaf extract pH (Girish et al., 2017). Leaf extract pH is the measure of hydrogen ion activity and mostly depends on the relative amounts of the adsorbed hydrogen and metallic ions (Walter et al., 2008). It is a good measure of the intensity of the acidity and alkalinity of the suspension. For the transfer of tiny molecules involving hormones and intracellular trafficking of a vesicle, the balance of pH in cell sections is significant. At alkaline pH, the detoxification mechanism is developed in plants. Hence, when leaf extracts become at neutral or alkaline pH, trees are considered tolerant species. The relative water content (RWC) of the leaf improves transpiration, gives plants a cooling sensation, and assists in restoring vigor during droughts. As a result, the amount of water in the leaves drives the engine that extracts minerals from the soil through the roots of the plants (Sahu et al., 2020). Besides, increasing in RWC of the leaves under pollution stress helps to maintain the biochemical balance of trees (Tanee & Albert, 2013; Nadgórska-Socha et al., 2017).

To manage air pollutants using green belts, some socioeconomic and biological indicators are used to evaluate the anticipated performance index (API) (Govindaraju et al., 2012). The API is more suitable than APTI in mitigating air pollution, which has been used as an index to determine the ability of tree species in the clean-up of air pollutants (Karmakar & Padhy, 2019). The API values give an ideal concept to classify different tree species for the green belt development. Accordingly, API is very important in the selection and evaluation of trees that can be used in the establishment of green belts (Sahu & Sahu, 2015; Rai, 2016).

Up to our knowledge, there is no evaluation of the suitability of the present cultivated tree species in green belts around the cement factories in Egypt. Therefore, The present study aimed at evaluating the potential of four tree species (*Eucalyptus camaldulensis*, *Casaurina equisetifolia*, *Conocarpus lancifolius*, *Ficus* *benjamina*) growing in the green belt of 21 cement factories in Egypt to mitigate air pollution through assessing their air pollution tolerance index (APTI) and anticipated performance index (API), compared with two reference sites. Our null hypothesis is that not all of them are tolerant to cement air pollution.

Materials and Methods

Study area and selected tree species

Twenty-one cement factories are distributed in many Egyptian provinces; from Alexandria at the north to Qena at the south (Fig. 1). Most of these factories are in desert areas, with variable distances from residential areas. The sampling sites of the studied tree species, geographical coordinates, and location type are shown in Table 1. Two reference sites were selected in the desert areas away from the residential areas at Belbis city (Sharkeya Governorate) and 6 October City (Giza Governorate).

Ficus benjamina L. (Weeping Fig in English, Family Moraceae) is a large, spreading fig tree, originates in Asia, and is frequently introduced as an ornamental tree. It is cultivated in public areas as a hedge or roadside plant. It grows rapidly up to 6 m and tolerates shade, drought, and a wide range of soil types (Quattrocchi, 2012). *C. equisetifolia* L. (Casuarina in English, Family Casuarinaceae) is a fast-growing species producing a lot of seed and it competes with other plants in disturbed sites. It forms a dense canopy and has negative impacts on other flora, fauna, and soil characteristics. It originates in Australia and is then distributed or cultivated in many other countries (Miller et al., 2002). *E. camaldulensis* Dehnh. belongs to the Myrtaceae Family and is commonly known as red gum. It grows up to 20 m, while stem diameter at breast height can reach >2 m. It originates in Australia and is then planted in many countries in the world including Egypt. The tree is tolerant to extreme drought and soil, salinity conditions, characterized by rapid growth and reproduction at a young age (Rejmanek & Richardson, 2011). *C. lancifolius* Engl. (Family Combretaceae) is an evergreen tree that originated from Southern Yemen and Somalia. It is one of the fastest-growing trees, producing large quantities of wood, providing strong poles and timber. It is useful as ornamental shade trees and windbreaks around irrigated farms. It is used for stabilizing riverbanks and improving poor, nutrient-deficient soil (Ali & Hassan, 2014).

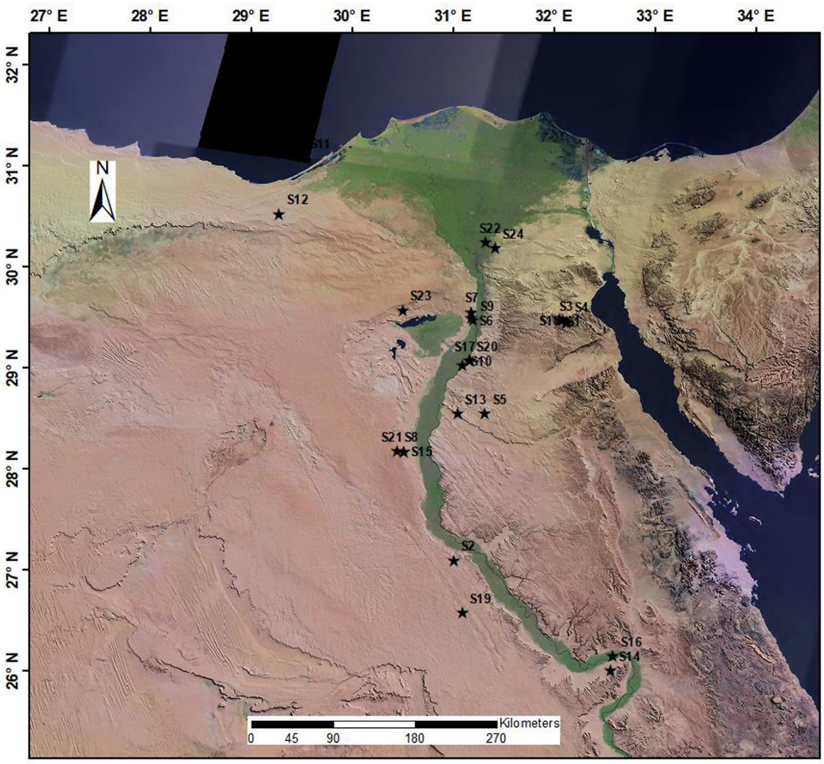

Fig. 1. The location map showing shows the sites of the studied cement factories in Egypt

TABLE 1. Province name, location type, and coordinates of the sampling cement factories studied s (S1-S21) and control s (S22-23) in Egypt

Site no.	Province	Latitude (N)	Longitude (E)	Location type
1	Suez	29° 48′12”	32° 05′ 19”	Desert
2	Assiut	27° 10′ 08”	31° 00′ 51”	Desert
3	Suez	29° 47′ 47”	32° 08′ 54”	Desert
4	Suez	29° 46′ 16”	32° 12′ 43”	Desert
5	Cairo	28° 55′ 09”	31° 31′ 53”	Desert
6	Cairo	29° 49′ 17”	31° 18′ 36”	Residential & agricultural
7	Cairo	29° 55′ 28”	31° 18′ 06”	Residential & Desert
8	Minya	28° 18′ 04”	30° 44′ 49”	Desert
9	Cairo	29° 47′ 21”	31° 19′ 55”	Residential & Desert
10	Beni Suef	29° 02′ 52”	31° 09′ 57”	Desert
11	Alexandria	31° 08′ 34”	29° 50′ 22”	Residential
12	Alexandria	30° 52′ 47”	29° 28′ 01”	Agricultural & Desert
13	Beni Suef	28° 55′ 12”	31° 04′ 38”	Desert
14	Qena	26° 01′ 35”	32° 56′ 22”	Desert
15	Minya	28° 17′ 56”	30° 51′ 32”	Desert
16	Qena	26° 15′ 06”	32° 58′ 06”	Desert
17	Beni Suef	29° 07′ 37”	31° 17′ 03”	Desert
18	Suez	29° 44′ 56”	32° 12′ 43”	Desert
19	Assiut	26° 58′ 05”	31° 09′ 10”	Desert
20	Beni suef	29° 07′ 33′	31° 16′ 07”	Desert
21	Elminya	28° 17′ 39”	30° 51′ 22”	Desert
Control 1	El sharkeya	30° 24′ 22”	31° 32′ 13”	Agriculture
Control 2	El Giza	29° 57′ 44”	30° 50′ 39”	Industrial
Control 3	El sharkeya	30° 18′ 51”	31° 41′ 44”	Mixed

The green belt surrounds each cement factory from all directions. Each green belt consists of 2-3 rows of trees, three meters apart. The distance between each neighboring tree in the same row is about three meters. The number of sampled sites for *F. benjamina*, *C. equisetifolia*, *E. camaldulens,* and *C. lancifolius* were 16, 10, 9, and 13 sites, respectively in the polluted sites. Simultaneously, the leaves of the target species were sampled from 1-2 reference sites. The irrigation water used for the target tree species in all polluted and control sites was sanitary, while the soil type was sandy soil.

Leaf sampling and chemical analysis

Sampling was carried out during 2017 and 2018 for fresh healthy, fully mature, and expanded leaves from the external lowermost parts of the tree canopies and in all directions (1.5-2m above soil surface). 10-15 leaves replicates were collected from the target species (*E. camaldulensis, C. equisetifolia, F. benjamina, C. lancifolius*) near twenty-one cement factories in Egypt, as well as two reference control sites. Ten to fifteen leaf replicas were collected for each tree species from four random quadrates in the green belt representing all the geographical directions. The leaves of each tree species from each quadrat were packed in polyethylene bags and transferred to the laboratory in ice tanks. The samples were washed once with tap water and twice with distilled water to remove any wastes or dust on the surfaces, and then used for the following laboratory analysis.

Total chlorophyll content (TCH)

One gram of clean fresh leaves for each sample was crushed and homogenized in a pestle with a mortar with 30mL of 80% acetone and kept for 15min for complete extraction. Tubes were centrifuged at 5000rpm for 5min. The supernatant was collected, and the volume was made up to 25mL with 80% acetone. The absorbance of the solution was measured at 645nm, and 663nm using a spectrophotometer against blank. The total chlorophyll content (in mg g^{-1} of fresh weight) was calculated with the following formula according to Arnon (1949).

$$TCH\ (mg/g)= (20.2\ (A_{645}) \pm 8.02\ (A_{663})\ {*}V)/\ 1000\ {*}\ W\ (g)$$

where, A_{645} and A_{663} are the absorbances at 645 and 663 nm, respectively; V is the total volume of the extract (ml), and W is the leaf weight in gram.

Leaf extract pH

About 5.0g of fresh leaves were crushed to a paste in 10mL deionized water, centrifuged and the pH of the supernatant was measured by pH meter (PHS-3C model).

Relative water content

The relative water content (RWC) of each clean leaf sample (10 leaves per species, 3 replicas/ sampling site) was estimated by weighing its fresh weight, then immersing the fresh leaves overnight in deionized water, and then re-weighed to get the turgid weight. Then, the samples were oven-dried at 70°C overnight then re-weighed again to obtain the dry weight. RWC was calculated by the following formula (Singh, 1991):

$$RWC\ (\%)= [(FW-DW)]\ /\ [(TW-DW)]\ x\ 100$$

where, FW is the fresh weight, DW is the dry weight, and TW is the turgid weight.

Ascorbic acid analysis

Ascorbic acid (AA) content was estimated using the spectrophotometric method by Bajaj & Kaur (1981). Three grams (3g) of fresh leaves were homogenized with 12mL of the extracting solution (5g oxalic acid and 0.75g EDTA in 1L of deionized water). Then, 3mL of phosphoric acid, 3mL 5% v/v sulphuric acid, followed by 6 ml of 5% ammonium molybdate reagent, and 9 ml of water were added to the sample. After 15min, the absorbance was measured at 760nm against a reagent blank using a UV-Visible spectrophotometer. The AA concentration was then extrapolated from a standard ascorbic acid curve. The standard curve was prepared by using different concentrations of AA by following the same method.

Air pollution tolerance index (APTI)

The air pollution tolerance index was calculated according to Singh & Rao (1983), Singh et al. (1991) as follow:

$$APTI = [AA\ x\ (TCH+P) + R]\ /\ 10$$

where, AA is ascorbic acid (mg g^{-1} fresh wt.), TCH is the total chlorophyll content (mg g^{-1} fresh wt.), P is the leaf extract pH, and R is the relative water content (RWC) %) of the leaves. The APTI values help to identify the tolerant and sensitive tree species. Species are divided into several categories according to their APTI value: < 1, Very Sensitive (VS), 1–16: Sensitive (S), 17–29: Intermediate (I), 30–100: Tolerant (T).

Anticipated pollution index (API)

The Anticipated Pollution Index (API) in the studied tree species was calculated by summating the results of APTI with some pertinent biological and socio-economic parameters such as tree habit, canopy structure, and type of tree, laminar structure, and economic value (Abbas et al., 2013). Based on these criteria, different grades (+ or -) are assigned to trees (Table 2). Different trees are scored according to their grades. The criteria used for calculating the API of different tree species are given in Table 3 according to Kaur & Nagpal (2017) and Banerjee et al. (2018).

Statistical data analysis

One-way ANOVA was used to compare the analyzed biochemical parameters in polluted and control sites for each tree species. The same test was used to compare the average values of the biochemical parameters of the studied tree species in polluted sites followed by a post hoc test and descriptive statistics including the maximum, minimum, and variance. Statistical analysis was carried out using SPSS software (SPSS, 2012).

Results

The results of the biochemical parameters for the target species are shown in Tables 4-7 compared to reference sites. It is worth noting that all the analyzed biochemical parameters for each species were significantly varied among the sampling sites at $p < 0.05$ (data not shown).

Biochemical analysis

The average values of TCH were 1.31± 0.001, 2.18± 0.004, 2.11± 0.021, and 1.74± 0.02 (mg g^{-1} fresh weight) in *F. benjamina, C. equisetifolia, E. camaldulensis*, and *C. lancifolius* in the polluted sites. The values of TCH in the reference sites were higher than those in the polluted sites, but they were not significantly different at $p < 0.05$, except for *C. equisetifolia* (Tables 4-7). The lowest amount of TCH was 0.72 mg g^{-1} for *F. benjamina*, while the highest was 2.66 mg g^{-1} in *C. equisetifolia* tree, in the polluted and control sites.

TABLE 2. Gradation of tree species based on air pollution tolerance index (APTI) and other biological and socio-economic criteria

Grading character	Pattern of assessment			Grade allotted
Tolerance	Air pollution tolerance index (APTI)	Tolerance	7 - 8.5	+
			8.6 - 9.5	++
			9.6 - 10.5	+++
			10.6 - 11.5	++++
			11.6 - 12.5	+++++
Biological and socio-economic	Plant habit		Small	-
	Medium		+	
	Large		++	
	Canopy structure		Sparse/irregular/globular	-
	Spreading/crown open/semi dense		+	
	Spreading dense		++	
	Type of plant		Deciduous	-
	Evergreen		+	
	Laminar	Size	Small	-
			Medium	+
			Large	++
		Texture	Smooth	-
			Coriaceous	+
		Hardiness	Delineate	-
			Hardy	+
Economic Value			Less than three uses	-
	Three or four		+	
	Five and more		++	

TABLE 3. Anticipated performance index (API) of tree species

Grade	Score %	Assessment category
1	Up to 30	Not recommended
2	31-40	Very poor
3	41-50	Poor
4	51-60	Moderate
5	61-70	Good
6	71-80	Very good
7	81-90	Excellent
8	91-100	Best

TABLE 4. Biochemical analysis (mean ± Std), APTI, API%, and API Grade of Ficus benjamina tree species from polluted and control sites

Site no.	Total chlorophyll (mg/g)	pH of leaf extract	RWC (%)	Ascorbic acid (mg/g)	APTI	API%	API Grade	Assessment
2	1.32±0.010	6.70±0.10	87.05±0.01	1.14±0.02	9.62±0.010	75.0	6	very good
3	1.47±0.010	5.83±0.03	94.79±0.00	0.68±0.01	9.97±0.010	75.0	6	very good
4	1.32±0.030	7.40±0.05	94.72±0.00	0.92±0.02	10.27±0.01	75.0	6	very good
5	0.72±0.020	7.32±0.01	83.01±0.00	1.86±0.01	9.80±0.200	75.0	6	very good
6	0.89±0.010	7.08±0.02	90.75±0.05	1.73±0.01	10.45±0.00	75.0	6	very good
7	1.44±0.001	7.30±0.02	82.42±0.01	1.95±0.03	9.95±0.03	75.0	6	very good
9	1.58±0.020	7.40±0.01	90.49±0.03	1.65±0.05	10.53±0.01	75.0	6	very good
10	0.89±0.000	7.46±0.01	93.11±0.01	0.41±0.01	9.65±0.03	75.0	6	very good
11	1.08±0.01	6.18±0.02	95.78±0.00	0.84±0.04	10.19±0.01	75.0	6	very good
12	1.05±0.00	7.00±0.00	88.13±0.01	0.75±0.03	9.42±0.00	68.7	5	Good
13	1.47±0.00	6.55±0.00	89.84±0.01	0.92±0.02	9.72±0.01	75.0	6	Very good
14	2.21±0.00	7.06±0.02	89.07±0.01	0.82±0.00	9.67±0.07	75.0	6	Very good
15	1.18±0.01	6.60±0.05	69.43±0.01	1.85±0.00	8.38±0.08	68.7	5	Good
17	2.25±0.02	7.10±0.01	97.21±0.01	0.55±0.00	10.24±0.02	75.0	6	Very good
18	1.15±0.01	7.20±0.03	92.25±0.00	0.82±0.01	9.91±0.01	75.0	6	Very good
21	0.89±0.01	5.86±0.02	89.65±0.05	1.33±0.01	9.86±0.00	75.0	6	Very good
Average± SD	1.33±0.44	6.95±0.48	89.20±6.97	1.13±٠,٥٣	9.85±0.52	73.90±0.60	5.8	Very good
Control	1.57±0.02	7.60±0.00	89.49±0.01	0.28±0.03	9.21±0.01	68.75	5	Good
F-value	1.03	5.15	0.00	7.57	4.77	0.38	---	---
Significance	0.32	**0.04**	1.00	**0.01**	**0.04**	0.54	---	---

TABLE 5. Biochemical analysis, APTI, API, API%, and API Grade of Casaurina equisetifolia species from polluted area and control area

Site no.	Total chlorophyll (mg/g)	pH of leaf extract	RWC (%)	Ascorbic acid (mg/g)	APTI	API%	API Grade	Assessment
2	2.06±0.020	6.10±0.01	81.47±0.0	0.55±0.00	8.60±0.10	75.00	6	very good
5	2.30±0.000	6.55±0.05	91.20±0.00	0.72±0.02	9.76±0.01	81.25	7	Excellent
7	2.09±0.010	5.60±0.02	91.59±0.01	0.39±0.03	9.46±0.02	75.00	6	very good
8	1.90±0.050	6.12±0.02	90.32±0.00	1.43±0.03	10.18±0.02	81.25	7	Excellent
11	2.66±0.000	6.45±0.15	82.55±0.00	0.72±0.01	8.91±0.01	75.00	6	very good
12	1.75±0.010	6.24±0.01	81.88±0.00	0.42±0.02	8.52±0.00	68.75	5	Good
13	2.23±0.010	6.85±0.05	82.89±0.01	0.43±0.00	8.68±0.00	75.00	6	Very good
17	2.03±0.020	6.35±0.01	87.42±0.10	0.42±0.02	9.09±0.00	75.00	6	Very good
18	2.58±0.002	6.80±0.03	89.31±0.08	0.40±0.05	9.31±0.00	75.00	6	Very good
20	2.16±0.060	6.50±0.05	91.21±0.06	2.10±0.02	10.94±0.01	87.50	7	Excellent
Average± SD	2.05±0.52	6.29±0.39	86.83±4.16	0.68±0.39	9.24±0.57	76.8±5.1	6.2±0.63	Very good
Control	2.59±0.014	7.25±0.03	92.4±0.14	0.38±0.02	9.61±0.019	81.25±0.0	7	Excellent
F-value	5.047	16.489	4.459	1.251	0.341	2.039	---	---
Significance	**0.046**	**0.002**	0.058	0.287	0.571	0.181	---	---

TABLE 6. Biochemical analysis and APTI, APTI, API%, API Grade of Eucalyptus camaldulensis species from polluted area and control area

Site no.	**Total chlorophyll (mg/g)**	**pH of leaf extract**	**RWC (%)**	**Ascorbic acid (mg/g)**	**APTI**	**API%**	**API Grade**	**Assessment**
1	1.57±0.010	7.25±0.050	87.20±0.050	0.64±0.040	9.28±0.020	81.25	7	Excellent
2	1.38±0.040	6.24±0.040	88.92±0.000	0.91±0.010	9.59±0.010	81.25	7	Excellent
4	1.93±0.030	6.38±0.000	95.11±0.000	0.45±0.050	9.88±0.003	87.50	7	Excellent
6	2.62±0.000	5.65±0.000	87.55±0.050	0.47±0.010	9.14±0.040	81.25	7	Excellent
7	2.25±0.020	5.23±0.030	92.31±0.000	1.25±0.050	10.17±0.030	87.50	7	Excellent
8	2.23±0.070	5.87±0.010	87.29±0.010	0.90±0.100	9.46±0.000	81.25	7	Excellent
9	2.65±0.050	5.27±0.020	83.46±0.010	0.86±0.010	9.03±0.000	81.25	7	Excellent
10	1.90±0.100	6.49±0.010	80.13±0.010	0.55±0.050	8.47±0.000	81.25	7	Excellent
11	2.45±0.010	5.2±0.100	91.87±0.010	0.39±0.020	9.49±0.010	81.25	7	Excellent
Average± SD	2.11±0.021	5.95±0.025	88.20±0.012	0.71±0.033	9.39±0.002	82.64±2.76	7	Excellent
Control	2.53±0.013	7.48±0.033	93.43±0.067	0.46±0.017	9.81±0.034	87.5±0.0	7	Excellent
F-value	2.482	13.499	3.606	2.132	1.983	8.750	---	---
Significance	0.146	**0.004**	0.087	0.175	0.189	0.140	---	---

TABLE 7. Biochemical analysis and APTI, API, API%, and API Grade of Conocarpus lancifolius species from polluted area and control area

Site no.	Total chlorophyll (mg/g)	pH of leaf extract	RWC (%)	Ascorbic acid (mg/g)	APTI	API%	API Grade	Assessment
1	2.44±0.010	6.58±0.010	83.36±0.060	1.40±0.000	9.60±0.050	81.25	7	Excellent
9	2.04±0.040	6.40±0.050	83.45±0.050	1.55±0.000	9.65±0.050	81.25	7	Excellent
10	1.43±0.010	6.24±0.040	85.35±0.010	1.91±0.000	10.00±0.200	81.25	7	Excellent
12	1.75±0.050	6.53±0.000	84.37±0.000	1.74±0.030	9.88±0.010	81.25	7	Excellent
13	1.08±0.001	5.87±0.070	88.99±0.000	0.65±0.020	9.35±0.010	75.00	6	Very good
14	1.50±0.100	6.89±0.040	59.76±0.000	0.65±0.050	6.52±0.020	62.50	5	Good
15	1.17±0.010	5.88±0.000	68.88±0.010	1.14±0.040	7.69±0.010	68.75	5	Good
16	2.14±0.030	5.88±0.015	85.26±0.010	0.79±0.050	9.16±0.010	75.00	6	Very good
17	2.15±0.050	6.09±0.020	89.15±0.030	0.31±0.045	9.17±0.020	75.00	6	Very good
18	1.46±0.010	6.55±0.050	93.63±0.030	0.70±0.000	9.92±0.000	81.25	7	Excellent
19	1.59±0.010	7.60± 0.000	85.68±0.030	0.62±0.000	9.14±0.000	75.00	6	Very good
20	2.48±0.030	6.76±0.060	83.12±0.020	1.73±0.030	9.91±0.011	81.25	7	Excellent
21	1.40±0.100	6.23±0.030	90.56±0.010	0.68±0.080	9.58±0.010	81.25	7	Excellent
Average± SD	1.74±0.02	6.42±0.00	83.20±0.01	1.07±0.01	9.20±0.00	76.34±6.09	6.4	Very good
Control	2.20±0.03	7.48±0.03	91.55±0.04	0.51±0.01	9.66±0.03	79.17±3.61	6	Very good
F-value	1.560	12.879	2.150	3.036	0.533	0.385	---	---
Significance	0.232	**0.003**	0.165	0.103	0.478	0.545	---	---

The values of leaf pH extracts for the studied species in the polluted sites were significantly different from the same species in control sites (at $P < 0.05$). pH values ranged from slightly acidic to slightly alkaline values (Tables 4-7). The average values of leaf pH extracts were 6.88± 0.009, 6.36± 0.01, 5.95± 0.025, and 6.42± 0.002 in *F. benjamina, C. equisetifolia, E. camaldulensis,* and *C. lancifolius* in polluted study sites, respectively. On the other hand, the average values of leaf pH extracts in control sites were 7.60± 0.073, 7.25± 0.03, 7.48± 0.033, and 7.48± 0.03 in *F. benjamina, C. equisetifolia, E. camaldulensis,* and *C. lancifolius*, respectively.

The values of RWC were significantly different between the polluted sites for each of the target species but were not significantly different from the control sites. The average values of RWC in polluted sites were 89.23% for *F. benjamina,* 86.98% for *C. equisetifolia*, 88.20% for *E. camaldulensis*, and 83.2% for *C. lancifolius*.

The results showed a significant variation in the average contents of ascorbic acid (AA) of the leaves of *F. benjamina* among the polluted (1.14± 0.011mg/g) compared with the reference (0.30± 0.01mg g^{-1}) sites (Table 4). Besides, the contents of AA were 0.68 ±0.39 mg g^{-1} in *C. equisetifolia*, 0.71± 0.033 mg g^{-1} in *E. camaldulensis*, and 1.07±0.01mg g^{-1} in *C. lancifolius*. In control sites, the AA contents were lower than but non-significantly different (at $P < 0.05$) from that obtained in the polluted sites for all species (Table 5-7).

APTI and API indices

The results showed that the air pollution tolerance index (APTI) was 9.85± 0.020 for *F. benjamina* in the polluted sites, while it was 9.21± 0.012 in the reference sites (F-value= 4.7 at $P < 0.04$). Besides, the APTI was 9.35± 0.013, 9.39± 0.0, and 9.20± 0.0 for *C. equisetifolia, E. camaldulensis*, and *C. lancifolius*, respectively, in the polluted sites; whereas, there were no significant differences between APTI for these species in the polluted and reference sites. The API percentage (for the studied tree species based on their APTI and different physiological and socio-economic criteria) is shown in Tables 4-9. The ranges of the API were 74.17-82.64% and 68.75-87.5 % in the polluted and reference sites, respectively. There were no significant differences in the values of API between the polluted and reference sites of each tree species. The average API for *F. benjamina* was 74.17 %, and it was considered as a very good performing species in the green belts of cement factories (Table 4). The API of *C. equisetifolia* (API = 76.88%) indicated that this species is classified as sensitive species and is considered a very good performing species in the green belts (Table 5). *E. camaldulensis* was classified as sensitive species (API = 82.64%) and it was considered as an excellent performing species in the green belts of cement factories (Table 6). The average API for *C. lancifolius* was 76.92 % and classified as a very good performing species in the green belts of cement factories (Table 7).

Comparison between the target species in polluted sites

By comparing the studied tree species in polluted sites, results showed that the mean TCH for all species was 1.76 among mg g^{-1} with a range of 0.72-2.66mg g^{-1}. The TCH value of *F. benjamina* was significantly different from all other species ($F= 11.55$, $P< 0.001$ (Table 8). Besides, the average pH of leaf extract of *F. benjamina* (6.95±0.48) was only significantly different from *E. camaldulensis* (6.10± 0.66). Mean API% of *E. camaldulensis* (83.33± 3.13) was significantly different ($F= 7.63$, $P< 0.001$) from other studied species in polluted sites. On the contrary, there were no significant variations among the studied species regarding RWC (%), AA (mg g^{-1}), and APTI in polluted sites (Table 8). Finally the mean grading of the four target tree species based on air pollution tolerance index and socioeconomic characteristics grades to assessment the anticipated performance index precent,grade and assessement recorded displayed in Table 9.

Correlation between the biochemical parameters and APTI

The significant correlations with a coefficient of determinations (R^2) > 0.5 between various biochemical parameters of the target tree species in the polluted sites and its APTI values are shown in Fig. 2. It is worth noting that the RWC (%) for all the studied species had high significant correlations with APTI (R^2 range: 0.6-0.8). Ascorbic acid contents of *E. camaldulensis* and *C. equisetifolia* had a high correlation with the APTI values in polluted sites ($R^2 = 0.64$ and 0.54, respectively).

TABLE 8. Statistical analysis of the biochemical characteristics of the target species (mean± SD) and its APTI and API

Species	Total chlorophyll (mg/g)	pH of leaf extract	RWC (%)	Ascorbic acid (mg/g)	APTI	API
Ficus benjamina	1.33±0.44[a]	6.95±0.48[a]	89.20±6.97[a]	1.13±0.53[a]	9.85±0.52[a]	74.17±2.20[a]
Casaurina equisetifolia	2.05±0.52[b]	6.29±0.39[ab]	86.83±4.16[a]	0.68±0.39[a]	9.24±0.57[a]	75.63±3.55[a]
Eucalyptus camaldulensis	2.08±0.43[b]	6.10±0.66[b]	88.13±4.53[a]	0.90±0.52[a]	9.55±0.72[a]	83.33±3.13[b]
Conocarpus lancifolius	1.79±0.48[b]	6.34±0.57[ab]	83.82±9.08[a]	1.02±0.54[a]	9.22±0.97[a]	77.23±5.80[a]
Statistics for all species						
Minimum	0.72	5.20	59.76	0.31	6.52	62.50
Maximum	2.66	7.60	97.21	2.10	10.94	87.50
Mean	1.76	6.47	86.94	0.96	9.48	77.08
Variance	0.30	0.37	48.89	0.27	0.57	25.49
F-value	**11.55**	**6.26**	2.04	2.17	2.22	**7.63**
Significance	**0.001**	**0.001**	0.12	0.11	0.10	**0.001**

TABLE 9. Mean ± standard error of grading of the target tree species based on pollution tolerance index and socioeconomic characteristics. S and E are socioeconomic grades

Species	APTI	APTI Grade	APTI (+)	S and E (+)	Total (+)	API	API%	API Grade	Assess-ment
Ficus benjamina	9.81±0.12	+++	2.82±0.10	9.0± 0.0	11.82±0.10	0.74±0.01	73.90±0.60	5.82±0.10	Very good
Casuarina equisetifolia	9.38±0.20	++	2.42±0.23	10.0±0.0	12.42±0.23	0.78±0.01	76.80±5.1	6.33±0.19	Very good
Eucalyptus camaldulensis	9.45±0.14	++	2.36±0.15	11.0±0.0	13.36±0.15	0.82±0.01	82.6±2.76	7.00±0.00	Excellent
Conocarpus lancifolius	9.29±0.24	++	2.53±0.17	9.88±0.13	12.25±0.23	0.77±0.01	76.34±6.09	6.31±0,20	Very good

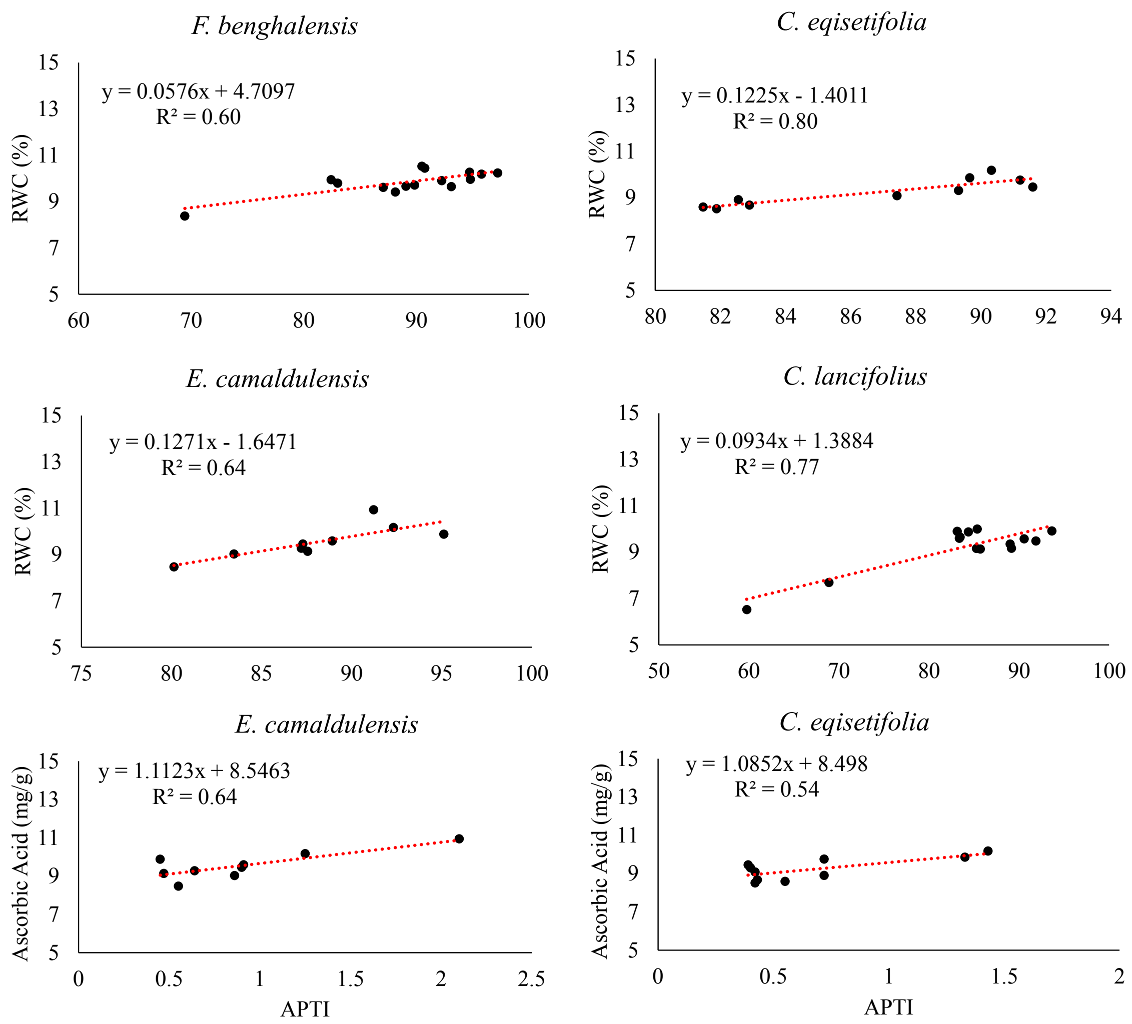

Fig. 2. Scatter plots of various biochemical parameters with APTI values of the studied tree species in polluted sites [Parameters with a high coefficient of determination correlations (R^2) > 0.5 are only shown]

Discussion

Photosynthetic pigment degeneration has been widely considered as an indicator of air pollution (Ninave et al., 2001). The amount of total chlorophyll is usually decreasing due to an increase in air pollution (Allen et al., 1987). The presence of high chlorophyll contents in the leaves of tree species reflects the tolerance of these species to air pollution stress (Santosh et al., 2008). Chandawat et al. (2011) reported that the chlorophyll contents of plants varied with the pollution status of the area, as well as the tolerance and sensitivity of the plant species. The Chlorophyll content of plant species correlates with photosynthetic activity such as growth, biomass development and varied from species to species depending on leaf age and pollutant concentration (Katiyar & Dubey, 2001). In this study, the target species had considerably high chlorophyll contents in control sites compared to polluted ones. Similar findings were reported by Rai et al. (2013) and Karmakar et al. (2021) for trees in polluted industrial areas.

The estimated pH of leaf extracts of the studied tree species in polluted sites was acidic compared to control sites. The presence of acidic pollutants such as Sulfur dioxide and Nitrogen oxides in ambient air emitted from the ideal combustion of fuel leads to lowering of leaf pH extracts. The lower pH values in leaves increase their tolerance to air pollution. Abedesfahani et al. (2013) reported that low leaf pH values in trees improve their resistance to air pollution. Kaur & Nagpal (2017) found that urban tree species in Punjab, India had acidic leaf pH extracts that increase their tolerance to air pollution. Rai et al.

(2013) and Roy et al. (2020) recorded that tree species grown in industrial areas showed acidic pH values, ranging from 5.0 to 7.0. The acidic nature may be due to acidic pollutants from the industrial emissions which change the pH of leaf sap towards acidic. Low pH reflects excellent correlation with and sensitivity to air pollutants and decreasing photosynthesis process in tress (Swami et al., 2004; Yan-Ju & Hui, 2008; Thakar & Mishra, 2010). Higher pH on industrial sites improves tolerance against air pollutants (Agarwal, 1986; Shannigrahi et al., 2011).

Relative water content (RWC)

The RWC is its water content relative to its complete hardness. It is related to the permeability of protoplasmic cells in cells, which causes loss of water and decomposition of nutrients in leaves. The high water content of the plant body helps to save its physiological parameter under abnormal conditions, such as exposure to air pollution (Innes & Haron, 2000). Similar findings were reported by Jyothi & Jaya (2010) who found that the trees exposed to air pollution have to repair their physiological balance under stress conditions contained with higher relative water content. Under air pollution conditions, transpiration rates are extremely high, which may lead to dehydration. Therefore, the repair of RWC by the plant may help in its relative tolerance to pollution (Verma, 2003). Thus, the high RWC of trees in industrial site samples may be responsible for the normal function of plant physiological processes (Rai et al., 2013; Roy et al., 2020). In the present study, the highest and lowest RWC values were recorded for *F. benjamina* and *C. lancifolius*, respectively. The difference in RWC is due to the difference among tree species that may be due to the dissimilarity in their capacity to tolerate stress conditions.

The present study revealed that the ascorbic acid (AA) contents in the target tree species were higher in the polluted sites compared to the control. Ascorbic acid is an antioxidant that increases the resistance of plants against air pollutants (Deepalakshmi et al., 2013). Plant species with a high amount of AA are tolerant to air pollutants (Keller & Schwager, 1977). It is an inherent detoxicant, which may prevent the impact of air pollutants in the plant tissues (Conklin, 2001). High Pollution load leads to induction of AA content in the leaves of tree species due to the increase in the production rate of reactive oxygen species (ROS) (Jyothi & Jaya, 2010). The results of the present study agree with the previous studies that indicated high production of AA intolerant species to air pollution (e.g., Begum & Harikrishna, 2010; Meerabai et al., 2012; Karmakar et al., 2021).

APTI is the ingrained quality of trees to register air pollution stress, which is presently the main apprehension, particularly in industrial areas. Trees that have high APTI results are tolerant to air pollutants, whereas trees with low APTI results show generally lower tolerance and are sensitive to air pollutants which act as an indicator for air pollution (Singh et al., 1991; Ahmad et al., 2021). A suitable estimation can be done on the resistance and sensitivity, of trees to air pollution using the APTI index (Sakhravi & Gholami, 2014). Estimation of the tolerance and sensitivity of tree species is fundamental for the decreasing of pollution in industrial areas (Marfaviporahmadi & Gholami, 2014; Gholami et al., 2016). Gholami et al. (2016) reported that the determination of the tolerance and sensitivity of tree species is essential to decrease pollutants in these areas. Anjali et al. (2018) reported that the Air pollution tolerance index difference from one plant species to another depends on the ability of plants to sustain the pollutants without appearing external damage. The plant species recorded different APTI values according to pH, chlorophyll content, RWC and ascorbic acid for that some species are sensitive and some are intermediately tolerant species. Tolerance to air pollutants changes from species to species depending on plants' ability to tolerate the impact of pollutants (Gholami et al., 2016). Besides, Noor et al. (2015) reported that tolerance of plants to air pollutants is specific for a specific site and depends on the concentrations and type of pollutants.

Assessment of APTI and API

APTI provides information on trees based on their sensitivity and tolerance to air pollutants using the physiological criteria and APTI grading. The present results showed that *E. camaldulensis, C. equisetifolia, F. benjamina*, *C. lancifolius* can be used as bio-indictors for cement air pollution since their APTI value presented in the ranged of sensitive species (APTI= 1 to 11). Compared to other studied tree species, Roy et al. (2020) reported that according to the APTI values, *F. benghalensis, F. religious,* and *Mangifera indica* are recommended as tolerant species to air pollution. The values of APTI vary for the same species according to the site (polluted vs. control) and among studies as well. For instance, in industrial areas in India, the values of APTI were 23.9 and 19.5 for *M. indica* and *F. benghalensis* (Karmakar et al., 2021), while Roy et al. (2020) reported 25.0 and 17.0 APTI values for the two species, respectively. Pandey et al. (2015) recorded APTI values of 16.9 and 26.0 for *M. indica* and *F. benghalensis*, respectively. In contrast, Shrestha et al. (2021) recorded *F. Benjamina* as sensitive species with an APTI value = 6.3 compared to 5.8 in the present study.

The recommended tree species for cultivation in industrial areas were estimated for several physiological and socio-economic as well as a few physiological parameters. APTI, tree habit, canopy structure, type of tree, laminar structure, and economic value. These parameters were subjected to a grading scale to estimate the anticipated performance of tree species as defended in reference (Sing & Rao, 1983). The API of the studied tree species indicated their suitability for cultivation in the green belts of the industrial areas. A comparison of the estimation criteria concerning grading parameters using the summation of the anticipated performance of tree species found those parameters to be quite similar. *Ficus benjamina* and *C. lancifolius* were sensitive to cement pollution according to their grades. Both species have a dense canopy of evergreen leaves, which provides more protection under pollution stress. The economic and aesthetic values of these tree species are well known, and it may be recommended for extensive cultivating as a first curtain in the green belts. *Eucalyptus camaldulensis* was graded as an excellent performer, while *C. equisetifolia* and *C. lancifolius* and *F. benjamina* were considered very good performers. Tree species found defined under the API category as excellent, very good, good, or moderate performers can be recommended for cultivation in green belts (Pandey et al., 2015; Dhankhar et al., 2015). The classification of the four studied tree species as very good and excellent performers under cement pollution stress according to their API values means their suitability for cultivation in the green belts of cement factories. Similar findings were reported by Pathak et al. (2011), Pandey et al. (2015) and Sarala & Sabitha (2011). The API grades for the target species was ranged from 5.83 (*F. benjamina*) to 7.0 (*E. camaldulensis*). By comparing these values with the API of other studied species in the world, we found that they lie in the same range or higher than that reported by Karmakar et al. (2021) for 18 tree species in India (range: 0-7). Karmakar & Padhy (2019) reported the API range 4-6 for the recommended tree species studied for the green belts of urban industrial areas. our target tree species perform very well compared to some tree species known for their fast growth but are defined as very poor performers under air pollution stress (e.g., *Dalbergia sissoo*, Kapoor et al., 2013).

Conclusions

The current study examined the suitability of currently four cultivated tree species in the green belts of 21 cement factories in Egypt. The results revealed that they have very good to excellent performers to the cement air pollution. Accordingly, more extension of the green belts around cement factories using these species is recommended This study showed that the estimated APTI and API values altogether for the tree species are very important for their selection for cultivation under industrial and urban conditions.

Conflicts of interest: No conflicts of interest have been declared.

Author contribution: Emad Farahat: conceptualization, experi ment design, data analysis, drafting the original manuscript, reviewing and editing, Omar Elawa: field and laboratory work, data analysis, drafting the original mns., Reviewing and editing, Nasser Abdelatif and Tarek Galal: conceptualization, editing and reviewing the mns.

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تقييم الاستخدام المحتمل لأربعة أنواع من الأشجار في الأحزمة الخضراء للتخفيف من تلوث الاسمنت للهواء في مصر

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يعد تلوث الهواء الناجم عن الانبعاثات الصناعية من المشكلات البيئية في العالم كله والتى لها آثار سلبية على البيئة وصحة الكائنات الحية. كما يمكن لأنواع من الأشجار تحسين جودة الهواء إلى جانب القيمة الجمالية للمناظرها الطبيعية. تتأثر تلك الاشجار بملوثات الهواء المختلفة وتظهر مستويات متفاوتة من التحمل والحساسية تجاه تللك الملوثات عند استخدامها كأحزمة خضراء حول مصانع الأسمنت. تهدف الدراسة الحالية إلى تقييم الاستخدام المحتمل لأربعة أنواع شجرية (الكافور، الكازوارينا، الكونوكربس والفيكس بنجامينا) والتي زرعت ونمت في الحزام الأخضر فى 21 مصنعًا للأسمنت في مصر، للتخفيف من تلوث الهواء وذلك من خلال تقييم مؤشر تحمل تلوث الهواء (APTI) ومؤشر الأداء المتوقع (API) ومقارنة ذلك بموقعين مرجعيين. وللتعرف على الأداء الوظيفي لهذه الأنواع الشحرية تم جمع الأوراق الطازجة من الأنواع الشجرية المختارة في نفس الوقت للقياسات المعملية الا وهى قياس المحتوى النسبي للماء بالاوراق (RWC)،حمض الأسكوربيك (AA)، الكلوروفيل الكلي (TCH) والرقم الهيدروجيني(pH) وذلك لحساب مؤشر تحمل تلوث الهواء (APTI) ومؤشر الأداء المتوقع (API). وأظهرت النتائج ان أداء شجرة الكافور ممتازً، وأن اداء اشجار الكازوارينا والكونوكربس أداءً جيدً جدا، بينما كان أداء اشجار الفيكس بنجامينا جيدًا فقط. أشارت قيم مؤشر الأداء المتوقع (API) لأنواع الاشجار المستهدفة إلى تحملها التلوث الناجم عن الأسمنت. ولذلك يوصى بزراعة تلك الأنواع المستهدفة على نطاق واسع في الأحزمة الخضراء لمصانع الأسمنت والمناطق الصناعية الحضرية الأخرى للتخفيف من تلوث الهواء الناتج عن تلك النوعية من الصناعة.