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Leaf Dust Accumulation and Air Pollution Tolerance Indices of Three Plant Species Exposed to Urban Particulate Matter Pollution from a Fertilizer Factory

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Abstract

To assess the dust interception efficiency and air pollution tolerance index (APTI) of three plant species *Cyperus alopecuroides*, *Pluchea dioscoridis* and *Ricinus communis* near fertilize factory in Abo-Zabaal village (Egypt) the present study was undertaken. The air quality has been measured and air pollution index was calculated for the different sites. Also relative water content, total chlorophyll, leaf extract pH and ascorbic acid content were measured. The highest dust deposition was detected in *Pluchea dioscoridis* (0.29) and *Ricinus communis* (0.19) and the values were slightly higher in winter than in summer. The APTI highest values were observed in *R. communis* (25.3) and the lowest ones were recorded in *C. alopecuroides* (12.16) and the values were slightly higher in summer than in winter. Thus plants can be used to intercept dust particles which are of potential health hazards to humans.

Keywords

Air pollution; APTI; Particulate matter; Dust deposition

Introduction

Air Pollution can be defined as the human introduction into the atmosphere of chemicals, particulate matter or biological materials that cause harm or discomfort to humans, or other living organism or damage the environment [1]. Air pollution is a major problem arising mainly from industrialization [2].

Particulate matter (PM) has been widely studied in recent years and the United Nations estimated that over 600 million people in urban areas worldwide were exposed to dangerous levels of air pollutants [3]. Atmospheric PM with aerodynamic diameter <10 µm (PM10) or <2.5 µm (PM2.5) are of considerable concern for public health [4-6]. It has been established that leaves and exposed parts of a plant generally act as persistent absorbers in a polluted environment [7].

Dust particles affect leaf biochemical parameters, bringing about some morphological symptoms. The extent of such effects depends on plant tolerance toward dust particles and on the chemical nature of the dust [8].

Sensitivity and response of plants to air pollutants is variable. The plant species which are more sensitive act as biological indicators of air pollution. The response of plants to air pollution at physiological and biochemical levels can be understood by analyzing the factors that determine resistance and susceptibility. Using plant, as indicator of air pollution is the possibility of synergistic action of pollutants [9].

Response of plants towards air was assessed air pollution tolerance index (APTI) which denotes capability of a plant to combat against air pollution. APTI determination of plants is important because in recent century by increasing industrialization, danger of desertification due to air pollution is threatening the environment. Screening of plants for their sensitivity/tolerance level to air pollutants is important because the sensitive plants can serve as bio- indicator and the tolerant plants as sink for controlling air pollution in urban and industrial areas [10].

The aim of this study is to determine the amount of dust accumulation on leaves and the APTI values of three plant species collected from different distance near Abo Zabal fertilizers factory, Egypt during winter and summer seasons.

Materials and Methods

Study area

The chemical fertilizer production company is installed on a site of 284,000 m^2, 30 km North East of Cairo El Maahd road at El Esmalia canal. Six sites were selected for the study Figure 1. One site was in front of the factory (site F) at 30°16'31.45" N and 31°22'51.67" E and another four sites were downwind direction and separated from each other and from the site at the factory with one kilo (Site 1 at 30°16'18.15"N and 31°22'23.53"E, 2 at 30°16'1.05"N and 31°21'53.83"E, 3 at 30°15'40.10"N and 31°21'24.45" E and 4 at 30°15'25.56"N and 31°21'14.55"E) and the another site was in the other direction (upwind) from the factory as control (site C) 30°18'0.85"N and 31°23'31.55" E.

The leaves of the following species were used for the determination of different parameters

Cyperus alopecuroides (Family *Cyperaceae*): With leaves up to as long as stem, stiff below, curved and somewhat flexuous above; soft; blades 15 mm wide, margins smooth.

Pluchea dioscoridis (Family *Asteraceae*): Its leaves are hairy, simple, lanculate, acute, serrate and sessile leaves which either elliptic or oblong and tapering towards the base.

Ricinus communis (Family *Euphorbiaceae*): The leaves are alternate, orbicular, palmately loped, 1–6 cm broad, with 6–11 toothed lobes, glabrous; long petiole.

Air quality analysis (SO_2, NO_x and suspended particulate matter (SPM))

Sampling and measurements were based on environmental protection agency [11] and American Standard test methods (ASTM:

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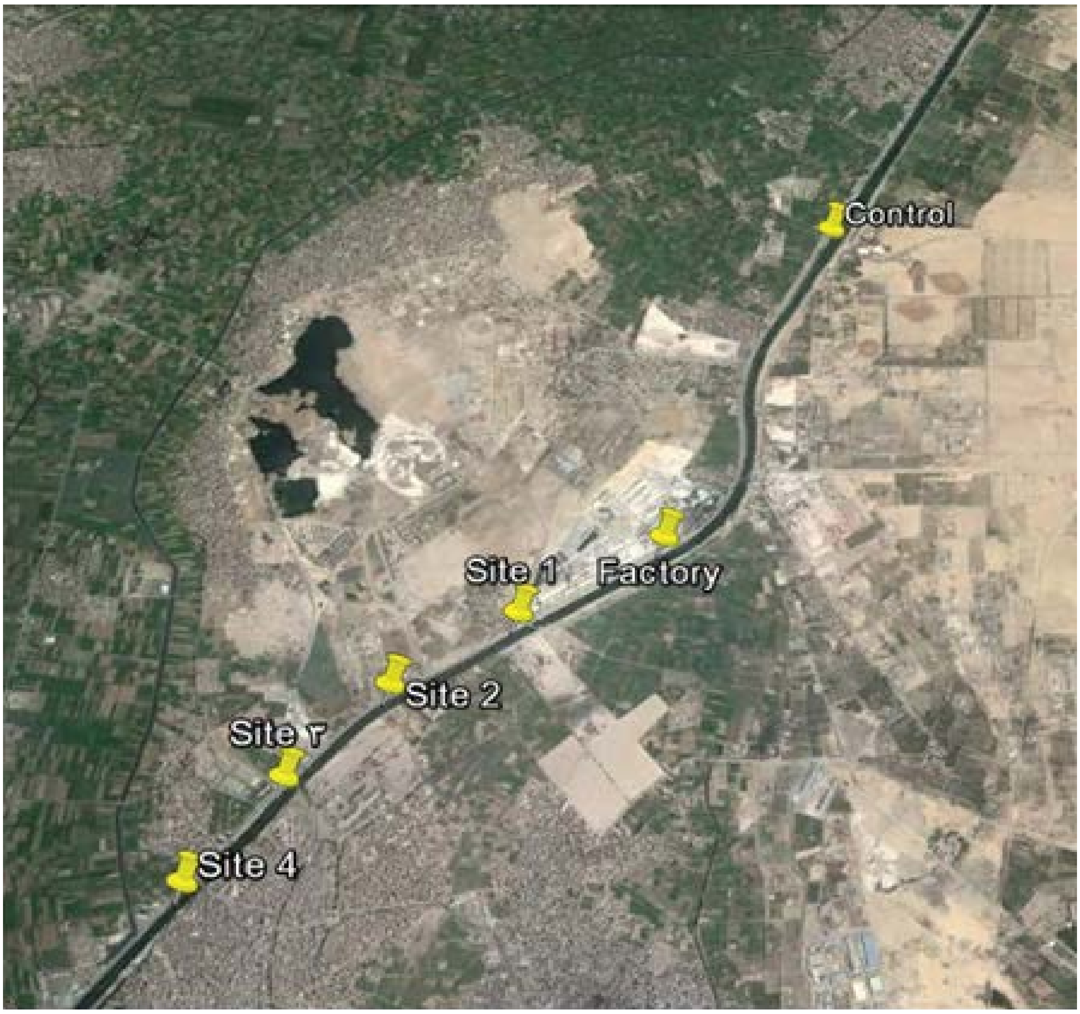

Figure 1: The study area showing the different sites.

ASTM D6216 and NOISH 0600) using Miran Gas Analyze and Thermo Dust meter [12].

Air pollution index (API): was calculated as described by Rao and Rao [13].

API=1/3 [(SPM)/(S_{SPM})+(SO_2)/(S_{SO2})+(NO_x)/(S_{NOx})] X 100 where S_{SPM}, S_{SO2} and S_{NOx} represent the ambient air quality standards for SPM, SO_2 and NO_x.

Index value Remarks (Ambient air quality standards taken for calculation of air pollution index 140 µg/m^3 for SPM, 60 µg/m^3 for SO_2 and 60 µg/m^3 for NO_x) 0-25 Clean air; 26-50 Light air pollution; 51-75 Moderate air pollution 76-100 Heavy air pollution; >100 Severe air pollution.

The leaf dust deposition was calculated and the result expressed as Dust accumulation per hour (gm^{-2} leaf area) [8].

Relative leaf water content (RWC) measured following the method described by Liu and Ding [14]**,** Total chlorophyll content (TCH) was done according to the method described by Maclachlan and Zalik [15]. For determine the leaf extract pH, 5 g of the fresh leaves was homogenized in 10 ml deionized water, and then filtered and the pH of leaf extracts was determined by Hanna GLP pH bench meter.

Ascorbic acid content (expressed as mg/g) was measured using spectrophotometric method described by Heath and Packer [16].

The air pollution tolerance indices of three plants species were determined following the method of Singh and Rao [17]. The formula of APTI is given as follow:

APTI=[A(T+P)+R]/10 Where A=Ascorbic acid content (mg/g), T=total chlorophyll (mg/g), P=pH of leaf extract, and R=relative water content of leaf (%).

(0 to 1=most sensitive; 2 to 16=sensitive; 17 to 29=intermediate; 30to100=tolerant).

Statistical analysis and data confirmation

Data were statistically analyzed ANOVA one way. The computations were done by using SPSS software Version (17.0). Values presented are means ± standard deviation (SD) of three replicates.

Results

The air pollution index for the six sites Table 1 showed that three sites (F, 1 and 2) were under severe air pollution (187.14, 153.8 and 128.33) and these sites the nearest to the fertilizer factory, and one site (3) was under heavy air pollution (92.5), and the control site and the 4Km downwind site (site 4) were light air pollution (42.46 and 49.76).

Dust accumulation on the surface of the leaves of *Cyperus alopecuroides, Pluchea dioscoridis* and *Ricinus communis* recorded in Table 2. The values were higher at the factory site (F) and decreased by increase the distance downwind from the factory. The values were slightly higher at winter than at summer and the highest values was on the leaves of *Pluchea dioscoridis* then *Ricinus communis*. *Cyperus alopecuroides*, is the least accumulator.

It is appear from Table 3 that the relative water content increased in sites F, 1, 2 and 3 if compared with sites C and 4, and the increase in values in the three plant species were higher in summer than in winter and the highest increase were in *R. communis*.

The study showed a change in chlorophyll a+b content recorded in (Table 4). The highest values were at sites C and 4 and the lowest were recorded at sites F, 1, 2 and 3. Total chlorophyll content values decreased as the distance from the factory decreased, and the highest reduction in chlorophyll was in *C. alopecuroides* followed by *R. communis* then *P. dioscoridis*.

Remarkable decrease in pH is shown in (Table 5). The value under the influence of the factory was recorded; the pH values were slightly acidic in sites F and 1 and alkaline to slightly alkaline in the other four sites. The lowest values recorded in *P. dioscoridis*. The values were higher in summer than winter.

Ascorbic acid content (Table 6) increased in the three species after exposure to air pollution, and the highest increases in values were recorded in *C. alopecuroides*.

Air pollution tolerance index recorded in (Table 7). Between the three plant species *R. communis* had the highest value of APTI. All the three species average of the APTI for the six sites were intermediate except *C. alopecuroides* was sensitive during winter.

Discussion

Plant leaves adsorb and, in smaller quantities, absorb particulate and gaseous pollutants [18]. Several studies have evaluated different plant species for their capacity in capturing air pollutants [19]. Dust interception and its accumulation in different plant species depends on various factors, such as leaf shape and size, orientation, texture, presence/absence of hairs, length of petioles etc., weather conditions and direction and speed of wind and anthropogenic activities [20].

The highest values of dust accumulation was shown on the leaves of *P. dioscoridis* which can be explained by the presence of hair on leaves with short leaf petiole that reduces movement of leaves in wind, while the lowest values were on *C. alopecuroides* which may be explained by the smooth texture of the long leaves that help the leaves to flutter during wind, and the vertical position of the leaves which prevents dust retention and in case of *R. communis* it lies in between as it has no hair to hold the dust and its texture not smooth

Table 1: Ambient air quality and air pollution index for different sites during summer and winter of 2012.

Sites		Season	Air pollution parameters				Air pollution index	
			CO mg/m³	SO_2 µg/m³	NO_2 µg/m³	SPM10 µg/m³		
Control	C	Summer	3	40	33	50	42.46	Light air pollution
		Winter	2.8	37	32	52	40.7	Light air pollution
factory	F	Summer	5.5	166	98	170	187.14	Severe air pollution
		Winter	5.2	157	96	178	182.9	Severe air pollution
Km distance downwind from factory	1	Summer	4.2	122	95	140	153.8	Severe air pollution
		Winter	4.1	119	91	147	151.67	Severe air pollution
	2	Summer	3.8	100	89	98	128.33	Severe air pollution
		Winter	3.4	93	84	100	122.14	Severe air pollution
	3	Summer	3.4	70	64	76	92.5	Heavy air pollution
		Winter	3.2	67	56	82	87.85	Heavy air pollution
	4	Summer	3.1	44	40	55	49.76	Light air pollution
		Winter	3	42	37	56	47.22	Light air pollution

Table 2: Mean values of Dust accumulation per hour (g m^{-2} leaf area) on the surface of leaves from the plant species (*C. alopecuroides*, *P. dioscoridis* and *R. communis*) at different sites (Values were represented as mean ± SD and the values with same letter in the same row are not significant).

Dust accumulation per hour (gm^{-2} leaf area)							
Plant species	Season	Sites					
		Control	Factory	Km distance downwind from the factory			
		C	F	1	2	3	4
C. lopecuroides	Summer	0.003 ± 0.001d	0.052 ± 0.005a	0.027 ± 0.005b	0.009 ± 0.0005c	0.004 ± 0.0001d	0.003 ± 0.0001d
	Winter	0.003 ± 0.001d	0.052 ± 0.005a	0.027 ± 0.005b	0.009 ± 0.0005c	0.004 ± 0.0001d	0.002 ± 0.0001d
P. dioscoridis	Summer	0.02 ± 0.006c	0.28 ± 0.003a	0.1 ± 0.01b	0.09 ± 0.006bc	0.05 ± 0.006c	0.02 ± 0.008c
	Winter	0.02 ± 0.004c	0.29 ± 0.001a	0.15 ± 0.01b	0.1 ± 0.004bc	0.07 ± 0.006c	0.03 ± 0.008c
R. communis	Summer	0.007 ± 0.002c	0.18 ± 0.02 a	0.072 ± 0.005b	0.037 ± 0.003b	0.032 ± 0.003 b	0.0125 ± 0.003c
	Winter	0.006 ± 0.002c	0.19 ± 0.02a	0.08 ± 0.005 b	0.05 ± 0.003b	0.03 ± 0.003b	0.009 ± 0.001c

Table 3: Relative leaf water content (RWC) percentage of the three pant species from different sites during summer and winter of 2012 (Values were represented as mean ± SD and the values with same letter in the same row are not significant). The percentage between every site and control were shown below the values.

Relative leaf water content (RWC) percentage							
Plant species	**Season**	**Sites**					
		Control	**Factory**	**Km distance downwind from the factory**			
		C	**F**	**1**	**2**	**3**	**4**
C. alopecuroides	Summer	76.3 ± 1.2c	92.1 ± 2.1a 20.7%	85.1 ± 0.8b 11.1%	81.1 ± 0.9b 6.2%	79.1 ± 0.3c 3.6%	75.6 ± 1c -1%
	Winter	79.9 ± 0.9c	94.3 ± 0.7a 18%	87.1 ± 0.4b 9%	82.3 ± 0.3c 3%	80.2 ± 1c 0.37%	78.3 ± 0.7c -2.1%
P. dioscoridis	Summer	65.9 ± 1.1e	85.2 ± 0.3a 29.2%	81 ± 0.7b 22.9%	77.4 ± 0.9c 17.5%	70.1 ± 0.6d 6.4%	66.3 ± 0.5e 0.6%
	Winter	70.3 ± 0.7d	87.1 ± 0.8a 23.8%	82.4 ± 1.2b 17.2%	78.1 ± 0.9c 11.1%	70.4 ± 0.5d 0.14%	70.2 ± 1.2d -1%
R. communis	Summer	56.3 ± 1.6d	81.1 ± 1.4a 44%	72.1 ± 0.9b 28%	66.9 ± 1.1c 18.8%	60.8 ± .3d 8%	57.2 ± 1.2d 1.5%
	Winter	61.2 ± 0.7d	83.2 ± 1a 35%	74.2 ± 0.9b 21.1%	70.3 ± 0.7c 14.8%	62 ± 1d 1.3%	60.1 ± 0.5d -1.1%

Table 4: Total chlorophyll content **(**mg/g fresh wt.) of the three pant species from different sites during summer and winter of 2012 (Values were represented as mean ± SD and the values with same letter in the same row are not significant). The percentage between every site and control were shown below the values.

Total chlorophyll content (mg/g fresh wt.)							
Plant species	**Season**	**Sites**					
		Control	**Factory**	**Km distance downwind from the factory**			
		C	**F**	**1**	**2**	**3**	**4**
C. alopecuroides	Summer	14.7 ± 0.3a	6.2 ± 0.2c -57.8%	6.6 ± 0.3c -55.1%	8.2 ± 0.1bc -44%	10 ± 0.1b -31.9%	13.6 ± 0.1a -7.5%
	Winter	14.06 ± 0.3a	5.2 ± 0.2c -63%	6 ± 0.3c -57.3%	7.6 ± 0.1bc -46%	9.66 ± 0.4b -31.3%	13.6 ± 0.7a -3.2%
P. dioscoridis	Summer	22.7 ± 0.15a	11.6 ± 0.2c -48.9%	12.9 ± 0.15c -43.25	13.1 ± 0.23c -42.3%	17.2 ± 0.3b -24.2%	21.5 ± 0.1a -5.3%
	Winter	21.9 ± 0.15a	10.6 ± 0.2c -51.6	11.9 ± 0.15c -45.7%	12.6 ± 0.23c -45%	16.63 ± 0.2b -24%	20.8 ± 0.6a -5%
R. communis	Summer	19.3 ± 0.2a	8.7 ± 0.3c -54.9	9.3 ± 0.34c -51.8%	10.4 ± 0.05bc -46.1%	12.5 ± 0.17b -35.2	18.2 ± 0.4a -5.7%
	Winter	17.24 ± 0.2a	7.9 ± 0.3c -54.2	8.6 ± 0.34c -50.1%	10 ± 0.05bc 41.9%	11.9 ± 0.4b -30.9%	18.2 ± 0.9a -5.7%

Table 5: Leaf extract pH of three plant species taken from different sites during summer and winter of 2012. (Values were represented as mean ± SD and the values with same letter in the same row are not significant). The percentage between every site and control were shown below the values.

Plant species	**season**	**Sites**					
		Control	**Factory**	**Km distance downwind from the factory**			
		C	**F**	**1**	**2**	**3**	**4**
C. alopecuroides	Summer	7.81 ± 0.2a	6.2 ± 0.2a	6.75 ± 0.5a	7.1 ± 0.3a	7.61 ± 0.13a	7.97 ± 0.1a
	Winter	7.85 ± 0.1a	6.25 ± .15a	6.83 ± 0.2 a	7.2 ± 0.19 a	7.73 ± 0.12a	8 ± 0.13a
P. dioscoridis	Summer	8.13 ± 0.3a	5.72 ± 0.2b	6.7 ± 0.3a	7.36 ± 0.2a	7.85 ± 0.2a	8.2 ± 0.2a
	Winter	8.19 ± 0.2a	5.81 ± 0.2b	6.91 ± 0.21a	7.61 ± 0.4a	7.91 ± 0.19a	8.3 ± 0.1a
R. communis	Summer	8.03 ± 0.5a	4.9 ± 0.15b	5.33 ± 0.3b	6.91 ± 0.13a	7.71 ± 0.21a	8.15 ± 0.3a
	Winter	8.12 ± 0.1a	5.1 ± 0.1b	5.37 ± 0.5b	6.97 ± 0.05a	7.98 ± 0.26a	8.2 ± 0.2a

to prevent dust retention. The influence of leaf characteristics on dust accumulation have also been studied [21,22].

The values of dust accumulation were slightly higher in winter than at summer. Prajapati and Tripathi [8] explained high dust accumulation in the winter season as wet surfaces of leaves may help in capturing dust. High wind speed may be the reason for the relatively lower dust accumulation in the summer than in winter.

As an important physiological factor, RWC is affected by the air pollution directly. It was proved that when plants suffered from air pollution, their stomatal density would increase [23], which led a decrease of the water content in plant tissues [24]. Thus higher water content within a plant body can help to maintain its physiological balance and enhance plants tolerance ability under the stress conditions (Agarwal and Tiwari, 1997). The increase in relative water content in polluted sites than the control had been recorded by Agbaire and Esiefarienhe [25], Gharge and Menon [26] and Rai et al. [27]. The same was recorded in this study. The values in winter are higher than summer that might be associated with a decrease in moisture availability.

Air pollution has strong influence on TCH in plant leaves, such as SO_2, an important pollutant affecting plants' health. In general, higher

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Table 6: Ascorbic acid content (mg/g fresh wt.) of the three plant species taken from different sites during summer and winter of 2012. (Values were represented as mean ± SD and the values with same letter in the same row are not significant). The percentage between every site and control were shown below the values.

Ascorbic acid content (mg/g fresh wt.)							
Plant species	Season	Sites					
		Control	Factory	Km distance downwind from the factory			
		C	F	1	2	3	4
C. alopecuroides	Summer	2.18 ± 0.072c	10.14 ± 0.14a 365.1%	8.60 ± 0.25b 294.4%	7.70 ± 0.05b 253.2%	3.92 ± 0.07c 79.8%	2.82 ± 0.08c 29.3%
	Winter	1.88 ± 0.13c	8.12 ± 0.30a 331.9%	7.11 ± 0.05a 278.2%	5.90 ± 0.44b 213%	3.02 ± 0.50c 60.6%	2.00 ± 0.21c 6.4%
P. dioscoridis	Summer	3.54 ± 0.26c	6.38 ± 0.25a 80%	5.80 ± 0.20a 63.8%	5.27 ± 0.30ab 48.8%	4.90 ± 0.20b 38.4%	4.00 ± 0.20bc 12.9%
	Winter	3.11 ± 0.33c	6.12 ± 0.30a 96.7%	5.30 ± 0.37a 70.4%	4.50 ± 0.55ab 44.6%	4.20 ± 0.10b 35%	3.21 ± 0.11c 3.2%
R. communis	Summer	4.75 ± 0.25d	12.66 ± 0.15a 166.5%	11.10 ± 0.1b 133.6%	8.82 ± 0.09c 85.6%	7.54 ± 0.28c 58.7%	5.08 ± 0.15d 6.9%
	Winter	3.21 ± 0.23d	9.30 ± 0.51a 189.7%	8.01 ± 0.36ab 149.5%	6.31 ± 0.40b 96.5%	4.90 ± 0.32c 52.6%	3.50 ± 0.21d 9%

Table 7: Air pollution tolerance index of the three plant species taken from different sites during summer and winter of 2012. (I=intermediate and S=sensitive)

Plant species	season	Sites						Average
		Control	Factory	Km distance downwind from the factory				
		C	F	1	2	3	4	
C. alopecuroides	Summer	12.53 S	21.78 I	19.99 I	19.89 I	14.81 S	13.64 S	Intermediate
	Winter	12.76 S	18.72 I	17.83 I	16.96 S	13.27 S	12.16 S	Sensitive
P. dioscoridis	Summer	14.62 S	19.57 I	19.37 I	18.52 I	19.19 I	18.51 I	Intermediate
	Winter	16.38 S	18.75 I	18.21 I	16.9 S	17.34 I	16.36 S	Intermediate
R. communis	Summer	18.61 I	25.32 I	23.44 I	21.95 I	21.31 I	19.1 I	Intermediate
	Winter	14.2 S	20.41 I	18.61 I	17.73 I	15.84 S	15.25 S	Intermediate

concentration of SO_2 will reduce the leaf TCH [28]. Photosynthesis was reduced in plants when the leaf pH was low [27]. Our results indicate that the TCH value in plant leaves decreased with higher concentration of SO_2 which is in agreement with previous studies [29,30].

The result of pH of the leaf extract was acidic in severe air pollution at the factory. The same result was recorded by Bakiyaraj and Ayyappan [10] and Nayak et al. [31]. According to Zhen [32], when plants are suffering from air pollutants (especially SO_2), their cellular fluid would produce massive H^+ to react with SO_2, which enters through stomata and intercellular space from air, so that H_2SO_4 is generated and then leaf pH reduces.

Ascorbic acid is a strong reluctant and it activates many physiological and defense mechanism. Its reducing power is directly proportional to its concentration [33]. Ascorbic acid content increased in the three plant species at the sites of high and severe air pollution. The same was reported by Agbaire and Esiefarienhe [25], Gharge and Menon [26] and Rai et al. [27].

The air pollution tolerance index (APTI) plays a significant role to determine resistivity and susceptibility of plant species against pollution levels. APTI is used to rank plant species in order of tolerance to air pollution [31].

The three plant species found to be intermediate tolerant at the sever air pollution at the factory site and the highest was *R. communis* which may be related to high ascorbic acid (AA) and total chlorophyll (TCH) than two species, the lowest was *C. alopecuroides* which can be related the low values of AA and TCH as suggested by Kuddus, et al., [34] that high AA and TCH related to tolerance species, so we can planted *R. communis* around the fertilizer factory for creating green environment and decrease the air pollution effect.

In conclusion plants can be used to intercept dust particles which are of potential health hazards to humans. The dust interception capacity of different leaves depends on leaf structure, phyllotaxy, presence/absence of hairs, presence of wax on leaf surface, length of petioles, and canopy structure. Plants with a waxy coating, rough leaf surfaces, and short petioles tend to accumulate more dust than plants with long petioles and smoother leaf surface.

APTI determinations are of importance because with increased industrialization, there is increasing danger of desertification due to air pollution. The results of such studies are therefore handy for future planning and may be helpful to bring out possible control measures. It is worth noting that combining a variety of parameters gave a more reliable result than when based on a single biochemical parameter.

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