Variation in air pollution tolerance index of plants near a steel factory: Implications for landscape-plant species selection for industrial areas

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Abstract: -Air pollution tolerance index (APTI) is used by landscapers to select plant species tolerant to air pollution. Four physiological and biochemical parameters including leaf relative water content (RWC), ascorbic acid (AA) content, total leaf chlorophyll (TCh), and leaf extract pH were used to develop an APTI. Twenty-three plant species growing near a Beijing steel factory, an air pollution point source, were collected during five dates from July 1 to October 16, 2001. Our data suggested that combining a variety of physiological parameters could give a more reliable result than those air pollution tolerance classifications based on a single biochemical parameter. Through the growing season, some species exhibited APTI variation related to changes in air temperature and water status of the plant. The results highlighted the need for APTI measurements to be conducted throughout the growing season, when evaluating pollution tolerance of individual species. Plant species tolerant or moderately tolerant to air pollution under a variety of environmental conditions include non-trees (shrub, herb, vine) such as *Metaplexis japonica*, *Ampelopsis aconitifolia* var. *glabra*, *Rhamnus parvifolia*, *Ziziphus jujuba* var. *spinosa*, *Pharbitis purpurea*, *Vitex negundo*, and trees including *Broussonetia papyrifera*, *Robinia pseudoacacia*, and *Ailanthus altissima*. The APTI of species indicated as an ideal candidate for landscape planting in the vicinity of polluting industry.

Key words: -Air pollution tolerance index; APTI; Leaf-extract pH; Leaf total chlorophyll; Ascorbic acid; Leaf relative water content

1 Introduction

The Beijing Capital Iron & Steel Factory (BCISF) in the west of Beijing, China is a significant and long term point source for air pollutants such as SO_2, CO, NO_2 and heavy metals. Mitigating this pollution is a high priority for both health of residents around the factory and amelioration of environmental conditions in the city. The reduction of emission either through curtailment of industrial activity [1] or scrubbing [2] has been suggested. However, neither offers a complete solution and both require significant economic costs. Therefore, landscape plantings in the factory's vicinity may offer an accessorial option [3].

Plants provide an enormous leaf area for impingement, absorption and accumulation of air pollutants to reduce the pollutant level in the air environment [4], with a various extent for different species [5].

Air pollutants can directly affect plants via leaves or indirectly via soil acidification [6]. When exposed to airborne pollutants, most plants experienced physiological changes before exhibiting visible damage to leaves [7]. Leaf conductance [8], membrane permeability [9], glutathione (GSH) concentration [10, 11], peroxidase activity [12] and $\delta^{13}C$ of leaf tissue [13] was used to estimate plant's tolerance. In addition, other studies showed that the impacts of air pollutants could have on the parameters also included ascorbic acid (AA) [11], chlorophyll content [14], leaf-extract pH [15], and relative water content [16]. However, these separate parameters gave conflicting results for same species, for example, *Ailanthus altissima* identified as sensitive to pollution using one parameter [17] but as tolerant using another [18]. For the reason that single parameter may not provide a clear picture of the pollution-induced changes, air pollution tolerance index (APTI) based on four important parameters has been used for identifying tolerance levels of plant species [4, 19].

Vegetation near BCISF has been exposed to a cocktail of air pollutants for more than 80 years. The ability of plant species to remove pollutants has been evaluated [20]. In this study, we aim to evaluate pollution tolerance of 23 plant species currently growing in the vicinity of BCISF by using the APTI method during the growing season, from the hot summer to the cooler autumn months. Thus, we could analyze seasonal variation of the parameters which influence pollution tolerance. The goal of this study was also to develop a gradation of air pollution tolerance that can be applied broadly in the selection of species in urban planting. Based on the previous view, the developmental stage, nutritional status and environmental factors were important factors in tolerance analysis [21]. The materials were thus collected from the site with similar environmental factors.

2 Materials and methods

Leaves of 23 plant species were collected from a hill northeast of the BCISF (39.90N, 116.32E) on five days from July 1 through October 16, 2001. Three replicates of fully mature leaves of each species were taken in the morning (9:00 a.m. to 11:30 a.m.). The selected plants were collected from sites with similar light, water and soil conditions. Samples were quickly transported to the lab in a heatproof container. Leaf fresh weight was taken immediately upon returning to the lab. Dry weight (DW) was adopted to express AA content and total chlorophyll content (TCh) referring to the previous methods [4]. Samples were preserved at 4 ℃ for AA, total chlorophyll, and leaf extract pH analysis.

2.1 Air temperature and humidity

Air temperature and humidity were measured at the time of sampling by using a Temperature and Humidity Measurement Instrument. For each sampling date, triplicate data were recorded at the same place. The average of the three data was considered as the weather factors at sampling time.

To obtain four parameters in APTI formula, samples were treated as follows:

2.2 Relative leaf water content (RWC)

Following the method described by Department of Biology, East China Normal University [22], leaf RWC was determined and calculated with the formula

$$RWC=(Wf-Wd)x100/(Wt-Wd)$$

Wf, which is fresh weight, was gained by weighing the fresh leaf pieces on a 4-digit balance. Then, these leaf pieces were weighed after immersing in water overnight to get Wt, which is turgid weight. Next, leaf pieces were blotted to dryness and placed in a dryer at 105 (2 hrs) and reweigh to get dry weight (Wd).

2.3 Total chlorophyll content [23]

For TCh analysis, 0.5 g fresh leaves material was grounded and diluted to 10 ml in distilled water. A subsample of 2.5 ml was mixed with 10 ml acetone and filtered. Optical density was read at 645 nm (D645) and 663 nm (D663). Optical density of TCh (C_T) is the sum of chlorophyll a (D645) density and chlorophyll b (D663) density as follows:

C_T = 20.2 (D645) + 8.02 (D663)

TCh (mg/g DW) was calculated as follows:

TCh = 0.1C_T x (leaf DW/leaf fresh weight)

2.4 Leaf extract pH

About 4 g of fresh leaves was homogenized in 40 ml deionized water and centrifuged at 7 000 g. Extract pH was measured with a photovolt pH meter at 25°C, using the Ag/AgCl Sure-Flow TM electrode, Modle No. 9165BN.

2.5 Ascorbic acid (AA) content analysis

Ascorbic acid content (expressed as mg/g DW) was measured using the colorimetric 2.6- dichlorophenol -indophenal (DIP)-method [10, 24]. For each sample, 1.0 g of fresh foliage was homogenized for 30 seconds in 40 ml oxalic acid extract solution at 6-8 , which was composed of 5.00 g oxalic acid and 0.75 g NaEDTA in 1 000 ml distilled water. The homogenate was centrifuged at 17 960 g for 20 minutes using low-temperature centrifuge at 0±5°C. To perform colorimetric determination, 1 ml of standard solution and 5 ml DIP solution were thoroughly mixed. Optical density at λ = 520 nm was measured at 25°C. Sample AA concentration is calculated on the standard regression of the corresponding dates.

2.6 APTI calculation
The APTI value is calculated referring to the formula previously provided [4, 25]:

APTI=[A(T+P)+R]÷10

Where A represents ascorbic acid; T, total chlorophyll; P, the leaf extract pH; and R, relative leaf water content.

2.7 Gradation of APTIs
The spectrum of APTI was divided as four grades of air pollution tolerance referring to a previous study [26]: tolerant (T or grade I), moderately tolerant (MT or grade II), intermediate (I or grade III), and sensitive (S). The tolerance grades were defined as follows:
(1) Tolerant: APTI > mean APTI+SD;
(2) moderately tolerant: mean APTI<APTI<mean APTI+SD;
(3) Intermediate: mean APTI-SD<APTI<mean APTI;
(4) Sensitive: APTI < mean APTI-SD.

To develop ranges of APTI values for each category, we separately calculated the mean APTI and its standard deviation for trees and non-trees especially including shrubs, vines and herbs in this article.

2.8 Data analysis
Data were analyzed by one way analysis of variance (ANOVA) using Statistical Program for Social Sciences (SPSS) 11.2 for windows.

3 Results
Samples were unavailable for *Rubia cordifolia* on August 20 and September 17, *Bothriochloa ischaemum* on September 17 and on October 16, *Lespedeza floribunda* and *Cleistogenes squarrosa* on October 16 when leaves turned to seasonally dry or due to hot and dry weather. Air temperature and humidity was measured to be shown in Table 1.

Table 1 Air Temperature and humidity at sampling site through the sampling season

Sampling dates	Air temperature ( )	Humidity (%)
July 1	29.2	74.0
July 18	36.0	43.0
August 20	34.0	60.0
September 17	26.3	43.0
October 16	22.5	32.5

3.1 Leaf RWC
The average dated leaf RWC varied from 60.3 mg/g DW for *Grewia biloba* to 89.5 mg/g DW for *Ampelopsis aconitifollia var. glabra*. There are significant changes (α=0.01 or 0.05) in 95.7% species, except *Ampelopsis aconitifolia* var. *glabra* with no significant variance at α=0.05. In general, 82.6% species held their highest RWC on July 1 and 87.0% showed lowest on July 18 (Table 2). Leaf RWC is positively correlated with air humidity with the coefficient of 0.73 (Table 3).

Table 2 The leaf RWC of plants from Beijing Capital Iron & Steel Factory on each sampling dates

Species No.	Life form	Leaf relative water content (mg/g.DW)					
		1-Jul	18-Jul	20-Aug	17-Sep	16-Oct	Ave.
1	DT	88.8	73.5	87.7	85.9	84.2	84.0
2	DV	91.0	90.2	90.2	89.8	86.5	89.5
3	AH/ sub-S[a]	86.9	63.0	83.2	55.6	71.4	72.0
4	PH	97.2	36.0	88.7	NA[b]	NA	74.0
5	DT	72.7	61.2	74.3	66.9	65.5	68.1
6	PH	99.6	44.6	88.3	64.5	NA	74.3
7	DT/S	92.2	81.8	89.9	83.1	86.3	86.7
8	DS	82.4	41.3	67.0	44.4	66.4	60.3
9	Sub-S	96.4	36.9	86.9	47.8	86.3	70.9
10	Sub-S	97.3	39.2	93.3	41.7	NA	67.9
11	PV	55.9	53.1	87.5	48.7	80.6	65.2
12	DV	94.9	67.9	73.3	71.0	66.3	74.7
13	AH	90.3	57.2	81.9	84.6	68.6	76.5
14	ET	86.2	71.1	79.0	73.2	76.3	77.1
15	ET	88.1	61.4	76.3	68.3	66.5	72.1
16	DS	89.1	54.0	74.1	65.3	68.4	70.2
17	DT/S	93.0	74.3	96.0	80.4	87.3	86.2
18	PH	94.3	60.5	NA	NA	64.1	73. 0
19	DT	90.6	78.8	87.0	86.6	84.7	85.6
20	DT	86.0	76.1	77.1	77.5	76.8	78.7
21	DS	84.3	38.8	85.8	50.3	69.1	65.7
22	DS	84.8	32.5	68.5	50.0	75.1	62.2
23	DT/S	90.8	63.9	71.8	68.6	71.6	73.3

(1) In species No. column: 1 refers to *Ailanthus altissima*; 2. *Ampelopsis aconitifolia* var. *glabra*; 3. *Artemisia gmelinii*; 4. *Bothriochloa ischaemum*; 5. *Broussonetia papyrifera*; 6. *Cleistogenes squarrosa*; 7. *Cotinus coggygria*; 8. *Grewia biloba*; 9. *Lespedeza floribunda*; 10. *Lespedeza tomentosa*; 11. *Metaplexis japonica*; 12. *Periploca sepium*; 13. *Pharbitis purpurea*; 14. *Pinus tabulaeformis*; 15. *Platycladus orientalis*; 16. *Rhamnus parvifolia*; 17. *Robinia pseudoacacia*; 18. *Rubia cordifolia*; 19. *Sophora japonica*; 20. *Ulmus pumila*; 21. *Vitex*

negundo; 22. *Wikstroemia chamaedaphne*; 23. *Ziziphus jujuba* var. *spinosa*
(2) In life form column: D: deciduous; P: perennial; A: annual; E: evergreen; T: tree; V: vine; S: shrub; H: herb
(3) In leaf relative water content column: [a] perrenial short shrub, with ligneous shoots in the low part of plant and herby shoots in the upper part of plant. [b:] NA. non available

Table 3 Correlation coefficient between weather and four parameters of plants in APTI formula

	RWC	TCh	pH	AA
Temperature	-0.19	0.25	-0.17	-0.69
Humidity	0.73	0.96	-0.90	-0.73

3.2 Leaf TCh

Table 4 The leaf TCh of plants from Beijing Capital Iron & Steel Factory on each sampling dates

Species No.	Leaf TCh (mg/g.DW)					
	1-Jul	18-Jul	20-Aug	17-Sep	16-Oct	Ave.
1	7.40	4.85	8.42	2.94	5.49	5.82
2	7.98	6.40	6.27	6.53	3.53	6.14
3	6.83	3.80	5.72	3.06	4.82	4.85
4	5.48	2.09	2.73	NA[b]	NA	3.43
5	16.45	11.18	12.58	9.22	7.43	11.37
6	9.36	2.88	2.46	6.84	NA	5.39
7	6.08	4.72	4.41	3.68	2.65	4.31
8	3.55	5.14	3.82	2.99	4.09	3.92
9	4.33	3.04	7.88	4.37	3.85	4.69
10	6.95	4.59	6.79	3.31	NA	5.41
11	11.18	8.52	7.54	10.95	6.83	9.00
12	11.15	6.71	6.00	5.09	3.00	6.39
13	7.38	5.11	11.70	8.95	6.11	7.85
14	2.14	2.52	2.16	2.73	2.11	2.33
15	3.28	2.25	2.69	2.62	2.67	2.70
16	5.35	6.35	7.17	7.36	5.51	6.35
17	7.07	9.16	9.66	8.10	6.92	8.18
18	19.07	12.58	NA	NA	14.67	15.44
19	5.22	4.94	4.45	4.98	5.07	4.93
20	3.92	2.47	2.92	1.87	2.05	2.64
21	4.01	3.01	3.75	2.43	2.58	3.16
22	3.17	2.48	2.11	2.37	1.58	2.34
23	3.04	3.55	3.35	2.93	4.15	3.40

(1) In species No. column: same numbers refer to same species names as in Table 2.
(2) In leaf TCh column: [b:] NA. non available

A range from 1.58 mg/g DW of *Wikstroemia chamaedaphne* on October 16 to 19.07 of *Rubia cordifolia* on July 1 was observed for TCh, with 78.3% species significantly changed at α =0.01 or 0.05. Through the sampling season, 65.2% species exhibited their own high TCh on July 1, and 13.0% showed low one on September 17 and October 16 (Table 4). TCh is well correlated with humidity at the correlation coefficient of 0.96 and with temperature of 0.25 (Table 3).

3.3 Leaf extract pH

Leaf-extract pH for different species significantly changed from 3.88 to 7.02 atα =0.01, with the lowest average recorded by *Pinus tabulaeformis* (4.27) and the highest by *Broussonetia papyrifera* (6.59). Leaf extract pH varied significantly (α =0.01 or 0.05) within 65% species through the sampling season. All species reached their own lowest leaf-extract pH on July 1 (Table 5). Leaf-extract pH has no significant correlation with air humidity (Table 3).

Table 5 Leaf-extract pH of plants from Beijing Capital Iron & Steel Factory on each sampling dates

Species No.	Leaf-extract pH				
	1-Jul	18-Jul	20-Aug	17-Sep	16-Oct
1	4.52	4.91	5.05	5.57	5.40
2	4.76	5.73	5.40	6.16	6.04
3	4.85	5.61	5.58	5.52	5.58
4	4.85	5.56	5.64	NA[b]	NA
5	5.43	7.02	6.73	6.80	6.99
6	5.10	6.30	6.10	6.40	NA
7	4.02	4.29	4.16	4.52	4.59
8	4.92	6.20	6.06	6.19	5.96
9	4.64	5.66	5.88	5.92	6.29
10	4.70	5.66	5.45	6.02	NA
11	4.92	5.86	5.98	5.90	6.07
12	4.70	5.52	5.76	5.80	5.73
13	4.90	5.67	5.83	5.84	6.00
14	4.01	4.51	3.88	4.17	4.79
15	4.39	5.15	5.19	5.34	5.40
16	4.88	5.80	6.08	6.27	6.39
17	5.02	6.27	6.05	6.36	5.98
18	4.66	5.57	NA	NA	6.21
19	4.98	6.14	5.98	6.34	6.11
20	4.95	5.97	5.78	6.08	5.88
21	4.59	5.47	5.19	5.46	5.54
22	4.73	5.44	5.51	5.72	5.89

23	4.86	6.09	5.72	6.00	5.89

(1) In species No. column: same numbers refer to same species names as in Table 2.
(2) In leaf-extract pH column: [b:] NA. non available

3.4 Leaf AA Content

Species showed significantly difference at α=0.01 for AA with the same trend as leaf RWC. The highest leaf AA content was recorded in *Metaplexis japonica* on October 16 (73.8 mg/g DW) and the lowest in *Wikstroemia chamaedaphne* on July 18 (0.5 mg/g DW). The AA content varied significantly (α=0.01/0.05) through out the sampling period for 69.6% species （Table 6）. No significant correlation exists between AA and air temperature (Table 3).

Table 6 The leaf AA content of plants from Beijing Capital Iron & Steel Factory on each sampling dates

Species No.	Leaf AA content (mg/g.DW)					
	1-Jul	18-Jul	20-Aug	17-Sep	16-Oct	Ave.
1	24.2	26.2	14.3	13.9	38.1	23.4
2	42.5	28.7	23.6	22.7	21.8	27.8
3	1.8	1.1	2.0	1.3	4.5	2.1
4	4.5	0.9	3.2	NA[f]	NA	2.9
5	1.9	32.4	36.7	32.3	30.3	26.7
6	6.4	1.7	6.3	3.6	NA	4.5
7	24.7	29.2	20.6	16.3	29.2	24.0
8	1.4	7.8	7.2	7.9	10.7	7.0
9	4.7	11.5	14.2	9.8	25.3	13.1
10	9.7	12.2	12.6	13.0	NA	11.9
11	35.3	18.0	44.1	29.7	73.8	40.2
12	18.9	10.5	16.6	15.5	13.2	14.9
13	7.4	18.8	11.8	33.0	34.1	21.0
14	11.0	16.8	16.6	8.8	13.5	13.3
15	16.3	10.6	10.4	9.3	13.7	12.1
16	21.9	22.0	23.1	23.8	29.0	23.9
17	4.5	20.8	21.6	16.2	18.8	16.4
18	4.0	5.1	NA	NA	17.8	9.0
19	9.8	8.2	10.4	12.5	8.8	9.9
20	16.8	18.0	14.0	17.5	16.1	16.5
21	17.0	21.0	27.3	26.9	20.3	22.5
22	8.0	0.5	9.1	13.9	20.9	10.5
23	24.1	26.0	24.2	25.5	33.4	26.6

(1) In species No. column: same number refers to the same species name as in Table 2.
(2) In leaf AA column: [b:] NA. non available

3.5 APTIs (Table 7)

The lowest APTI recorded during the study was for *Wikstroemia chamaedaphne* on July 18 (3.6), while the highest for *Metaplexis japonica* on October 16 (103.3). Species APTI was significantly different on the same sampling dates at α =0.01 and each species showed its own high APTI on different dates. However, the extent of APTI variance during the same sampling date varied significantly (α =0.01 or 0.05) among 73.9% species and insignificantly among 26.1% species.

Table 7 APTI of plants from Beijing Capital Iron & Steel Factory on each sampling dates

Species No.	APTI (mg/g.DW)					
	1-Jul	18-Jul	20-Aug	17-Sep	16-Oct	Ave.
1	37.7	32.9	28.0	20.4	49.9	33.8
2	63.2	43.8	36.6	37.8	29.5	42.2
3	10.7	7.3	10.6	6.7	11.8	9.4
4	14.3	4.3	11.6	NA[b]	NA	10.1
5	11.4	65.1	78.2	58.4	50.2	52.7
6	19.2	6.0	14.2	11.3	NA	12.7
7	34.2	34.4	26.6	21.7	29.7	29.3
8	9.5	13.0	13.8	11.6	17.4	13.1
9	13.8	13.7	28.2	14.9	34.2	21.0
10	21.0	16.4	24.8	16.3	NA	19.6
11	62.5	31.2	68.4	55.0	103.3	64.1
12	39.4	19.6	26.9	24.0	18.1	25.6
13	18.2	26.0	28.9	57.3	48.2	35.7
14	15.4	18.9	17.9	13.4	16.0	16.5
15	21.3	14.0	15.8	14.3	17.7	16.6
16	31.1	32.2	38.0	38.9	41.4	36.3
17	14.8	39.6	43.6	31.4	33.0	32.5
18	18.8	15.2	NA	NA	43.7	25.9
19	19.0	16.9	19.5	22.8	18.3	19.3
20	23.5	22.8	19.9	21.6	20.5	21.7
21	23.1	21.7	33.0	26.3	23.4	25.5
22	14.8	3.6	13.8	16.2	23.1	14.3
23	28.1	31.4	29.2	29.6	40.6	31.8

(1) In species No. column: same numbers refer to same species names as in Table 2.
(2) In APTI column: [b:] NA. non available

3.6 Gradation of APTIs

The gradation of APTIs was calculated referring to section 2.7. The overall mean APTI for trees was 27.6 ± 13.1; and for non-trees 26.0 ± 14.2.

Average APTI of shrub is higher than that of trees (Table 8).

Table 8 Plants' tolerance gradation through the sampling seasons

Species No.	Tolerance class of plants					
	1-Jul	18-Jul	20-Aug	17-Sep	16-Oct	Ave.
1	T[a]	MT[b]	I[c]	I	T	MT
2	T	T	MT	MT	I	T
3	I	S[d]	S	S	S	S
4	I	S	S	NA[e]	NA	S
5	S	T	T	T	T	T
6	I	S	I	I	NA	I
7	MT	T	I	I	I	MT
8	S	I	I	I	I	I
9	I	I	MT	I	I	I
10	I	I	I	I	NA	I
11	T	MT	T	T	T	T
12	MT	I	I	I	I	I
13	I	MT	MT	T	MT	MT
14	I	I	I	S	I	I
15	MT	I	I	S	I	I
16	MT	T	MT	MT	MT	MT
17	I	MT	MT	MT	MT	MT
18	I	I	NA	NA	MT	I
19	I	I	I	I	I	I
20	MT	I	I	I	I	I
21	I	MT	MT	MT	I	I
22	I	S	I	I	I	I
23	MT	MT	MT	MT	MT	MT

(1) In species No. column: same numbers refer to same species names as in Table 2.
(2) In tolerance class of plants column: [a] tolerant (T); [b] moderately tolerant (MT); [c] Intermediate tolerant (I); [d] Sensitive (S); [e] non available

4 Discussion and Conclusions

Ascorbic acid plays a role in cell wall synthesis, defense, and cell division [27]. It is also a strong reducer and plays important roles in photosynthetic carbon fixation [10], with the reducing power directly proportional to its concentration [28]. So it has been given top priority and used as a multiplication factor in the formula. High pH may increase the efficiency of conversion from hexose sugar to AA [4], while low leaf extract pH showed good correlation with sensitivity to air pollution [29]. Meanwhile, T, the TCh is also related to AA productivity [30] and AA is concentrated mainly in chloroplasts [31]. Photosynthetic efficiency was noted strongly dependent on leaf pH. Photosynthesis reduced in plants when the leaf pH was low [32]. Thus, in the proposed APTI formula, P, the leaf extract pH and T, the TCh have been added together and then multiplied with AA content. A high water content within a plant body will help to maintain its physiological balance under stress condition such as exposure to air pollution when the transpiration rates are usually high. High RWC favors drought resistance in plants [33]. If the leaf transpiration rate reduces due to the air pollution, plant cannot live well due to losing its engine that pulls water up from the roots to supply photosynthesis (1%-2% of the total). Then, the plants neither bring minerals from the roots to leaf where biosynthesis occurs, nor cool the leaf. Therefore, the product of AA and sum of leaf extract pH and total chlorophyll is added with R, the RWC in the APTI formula.

As stated in the result, AA content was well negatively correlated with temperature at –0.69 and with humidity at –0.73. pH is correlated with humidity at –0.9. RWC and TCh were well correlated with humidity. 82.6% species held their lowest RWC on July 18. It showed that many species responded to the dry weather by a RWC drop. Similarly, high leaf RWC was recorded in 87.0% species on July 1, when Beijing was experiencing a pouring and humid weather.

For most species, TCh declined during September and October when deciduous species prepared to shed their leaves in autumn [34]. In consistency with the previous results [14], these species with low leaf TCh in the late summer and early fall were also among the species with least tolerant to air pollution, but the relationship was not universally true. TCh of *Metaplexis japonica* decreased by 39.1% from 11.18 on July 1 to 6.81 mg/g DW on October 16, while its APTI increased by 65.2% from 62.5 on July 1 to 103.3 on October 16. This strongly emphasizes one parameter which may get a conflict result with APTI because one parameter such as TCh declines towards the end of the season while the situation is different for APTI [19].

The APTIs of most shrubs were higher than those of trees, suggesting that shrubs, in general, were more tolerant to air pollution than trees. This conclusion was consistent with previous results [17], which adopted *Superoxide Dismutase* (SOD) activity to estimate air pollution tolerance.

Some species studied here have been evaluated for air pollution tolerance by other workers[17, 35]. In this study, the tolerance gradation of species changed during the sampling period. For example, *Broussonetia papyrifera* was classified as sensitive on July 1, but tolerant on other sampling dates. Despite such variations, there is broad congruence between our results and those of others [17, 18, 35]. Six species, *Cotinus coggygria*, *Broussonetia papyrifera*, *Ulmus pumila*, *Sophora japonica*, *Platycladus orientalis*, and *Pinus tabulaeformis* show similar classifications of air pollution tolerance when compared to rankings in previous studies (Table 9). Although *Ailanthus altisima* and *Robinia pseudoacacia* show intermediate to tolerant in our scheme, they were both ranked as sensitive to air pollution when using the SOD method [17]. Because our method relies on four physiological parameters, it may be more reliable than those based on the activity of a single enzyme.

Table 9 Comparisons between this study and other similar studies

Species	Life form	Gradation		references
		This study	Other studies	
Cotinus coggygria	DT/S	MT,T,I, I,I (MT)	I,MT	[18]
Broussonetia papyrifera	DT	S,T,T, T,T (T)	I,MT	[18]
Ailanthus altissima	DT	T,MT,I, I,T (MT)	S,MT,I	[17, 18]
Robinia pseudoacacia	DT/S	I,MT, MT,MT, MT(MT)	S,MT,I	[17, 18,35]
Ulmus pumila	DT	MT,I,I, I,I (I)	T,MT,I	[17, 18, 32]
Sophora japonica	DT	I,I,I,I, I (I)	MT,I	[17,18]
Platycladus orientalis	ET	MT,I,I, S,I (I)	MT,I	[17, 18]
Pinus tabulaeformis	ET	I,I,I,S, I (I)	MT,I,S	[17, 18]

(1) In life form column: D refers to deciduous; E: evergreen; T: tree; S: shrub
(2) In Gradation column: T means tolerant; MT: moderately tolerant; I: Intermediate tolerant; S: Sensitive. In this study, Five species gradation data through the sampling season follows with an average in branket.

In summary, combining a variety of parameters can give a more reliable result than only based on a single biochemical parameter. Furthermore, air pollution tolerance affected by natural climate conditions such as temperature and humidity. This study also provides useful information to select tolerant species fit for landscape on sites continuously exposed to air pollutants. Species ranked as tolerant and moderately tolerant at most sampling dates should be considered in advance, including shrubs such as *Metaplexis japonica*, *Ampelopsis aconitifolia* var. *glabra*, *Rhamnus parvifolia*, *Ziziphus jujuba* var. *spinosa*, *Pharbitis purpurea*, *Vitex negundo*, the trees such as *Broussonetia papyrifera*, *Robinia pseudoacacia*, and *Ailanthus altissima*. Species ranked as intermediate tolerance at most collecting dates should be chosen for planting only when these species have strong ability to absorb the air pollutants, including *Cotinus coggygria*, *Periploca sepium*, *Lespedez*a *floribunda*, *Ulmus pumila*, *Wikstroemia chamaedaphne*, *Grewia biloba*, *Sophora japonica*, *Pinus tabulaeformis*, *Platycladus orientalis*. Species ranked as ‘sensitive’ should be avoided, such as *Rubia cordifolia*, *Lespedeza tomentosa*, *Cleistogenes squarrosa*, *Bothriochloa ischaemum*, and *Artemisia gmelinii*.

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