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Antioxidant Characteristics and Phytoremediation Potential of 27 Taxa of Roadside Trees at Industrial Complex Area

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ABSTRACT

In order to screen for the best species for mitigating air pollutants by plants at an industrial complex area, we investigated antioxidant capacity, lipid peroxidation and nitrogen content in the leaves of 27 taxa of woody plants that are mostly utilized as roadside trees. Among 27 taxa, the highest value of antioxidant capacity was given by *Cedrus deodara* (91.4%) and the lowest one was by *Firmiana simplex* (56.9%). At lipid peroxidation level, little malondialdehyde (MDA) was observed in *Lagerstroemia indica* and *Ginkgo biloba*, but *Platanus occidentalis*, *Castanoposis cuspidata* var. *sieboldii*, *Machilus thunbergii* and *Juniperus chinensis* showed high MDA content. Antioxidant capacity of the deciduous woody plants was not significantly different in comparison with that of the evergreen ones. But MDA content of the deciduous woody plants was lower than that of the evergreen ones. The 27 taxa of woody plants appeared to be classified into four types: those of high antioxidant capacity and low lipid peroxidation, those of high antioxidant capacity and high lipid peroxidation, those of low antioxidant capacity and low lipid peroxidation, and those of low antioxidant capacity and high lipid peroxidation. The taxa included in these types are 7 (first type), 6 (second one), 8 (third one) and 6 (fourth one) taxa. First or second type species which have a high antioxidant capacity represented low nitrogen content in their leaves. However, third or forth type species which have low antioxidant capacity showed high nitrogen content in their leaves. *Metasequoia glyptostroboides*, *Platycarya strobilacra* and *P. occidentalis* which belong to the first or second type had extraordinarily high antioxidant capacity and high nitrogen content. Thus, three species are considered to be good phytoremediators for an industrial complex area.

Key words **: Lipid peroxidation, Malondialdehyde, Nitrogen, Phytoremediator**

I. INTRODUCTION

Interest in the pollutants and in their effects on living organisms has increased in the last decades as a consequence of the rise in their ground-level concentration and of the widening of their diffusion areas. The current levels of the pollutant are high enough to exceed the tolerance threshold of many plant, thus impairing plant growth, reducing crop yields and altering the composition of plant communities. In Ulsan Industrial

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Complex Area, Korea, the average SO_2, NO_2 and O_3 concentrations during May to September 2004 were reported to be 0.015, 0.020 and 0.024 μL L^{-1}, respectively, whereas the average SO_2 level per 1 hour (0.15 μL L^{-1}) and 24 hour (0.05 μL L^{-1}) exceeded 150 and 49 times, and the average O_3 level per 1 hour (0.10 μL L^{-1}) and 8 hour (0.06 μL L^{-1}) exceeded 73 and 213 times (Ministry of Environment, 2005).

In fact, pollutant is able to induce, at the physiological and biochemical level, subtle changes, which can lead to different plant responses. Therefore, much attention has been paid to understand the mechanisms of action and reaction to the pollutant.

From many epidemiological studies, it has been shown that this pollution causes respiratory diseases combined or not with other air pollution such as ozone, sulfur dioxide, and particulate materials less than 2.5 μm (Brunekreef and Holgate, 2002). Plants are also affected by NO_2 exposure, that causes reduction of net photosynthesis, respiration, stomatal conductance, enzyme activities and growth (Wellburn, 1994).

On the other hand, plants take up NO_2 from atmosphere (Hill, 1971; Rogers *et al.*, 1979) and assimilate its nitrogen into organic nitrogenous compounds through primary nitrate assimilation pathway (Rogers *et al.*, 1979; Yoneyama and Sasakawa, 1979). NO_2 can also be converted to alternative nitrogen compounds, which indicates that NO_2 should be metabolized through a pathway that is different from that of primary nitrate assimilation (Morikawa *et al.*, 2004). These indicate that plants can utilize NO_2 at least to some extent, as a nitrogen fertilizer.

In urban or industrial complex, however, plants often experience harsh environmental condition such as NO_2 and O_3. These conditions can inhibit growth and development, reduce yield and, in extreme cases, can inflict lethal injuries to the plant. To ensure survival, plants have evolved a range of response strategies to the various abiotic stresses likely to be encountered. The responses to a specific stress may vary with the genotype (Deepak and Agrawal, 2001; Azevedo Neto *et al.*, 2006); nevertheless, some general reactions occur in all genotypes. At the whole plant level, the effect of stress is usually perceived as a decrease in photosynthesis and growth associated with alteration in carbon and nitrogen metabolism (Cornic and Massaci, 1996; Mwanamwenge *et al.*, 1999; Law and Crafts-Brander, 2001; Han *et al.*, 2004), and reactive oxygen production (Turcsanyi *et al.*, 2000; Schwanz and Polle, 2001).

Plant responses against several pollutants are divided into avoidance and resistance. The avoidance response was established through the stomatal closure to prevent pollutants from inflowing into plant cell. However resistance response uses defense system in order to mitigate the toxicity of the absorbed pollutants in plant cells. One of the defense system is antioxidant system against environmental stress. Abiotic stresses lead to oxidative stress through an increase in reactive oxygen species (ROS), such as superoxide ($O_2^- \cdot$), hydrogen peroxide (H_2O_2) and hydroxyl radicals ($OH \cdot$) (Alscher *et al.*, 1997; Mittler, 2002; Neill *et al.*, 2002). These ROS are highly reactive and can alter normal cellular metabolism through oxidative damage to lipids, proteins and nucleic acids (Mckersie and Leshem, 1994; Alscher *et al.*, 1997; Imlay, 2003).

To mitigate the oxidative damage initiated by ROS, plant has developed a complex defense antioxidative system, including low-molecular mass antioxidants as well as antioxidative enzymes, such as superoxide dismutase (SOD), catalase (CAT), ascorbate peroxidase (APX), guaiacol peroxidase (GPX) and glutathione reductase (GR) (Mckersie and Lesshem, 1994; Noctor and Foyer, 1998).

Another tolerance maker to abiotic stress is malondialdehyde (MDA) content, a product of lipid peroxidation. It has been considered as an indicator of oxidative damage. Thus, cell membrane stability has widely been utilized to differentiate tolerant and sensitive cultivars (Meloni *et al.*, 2003; Azevedo Neto *et al.*, 2006).

Many reports have analyzed the impact of pollutant on biochemical and physiological variables in plant species. However, most reports didn't consider their phytoremediation ability of air pollution. We tried to screen the plant species that have high antioxidant system as well as high phytoremediation from roadside trees in industrial complex area. Here we report on our analysis of antioxidant capacity, lipid peroxidation and N content in the leaves of 27 plant taxa among urban roadside trees.

II. MATERIALS AND METHODS

2.1. Plant materials

In this study, 27 taxa of roadside trees were collected from Ulsan Industrial Complex Area in Korea (Table 1). Annual average air temperature, mean relative humidity and precipitation of Ulsan in 2005 were 12°C, 61%, and 1428 mm respectively. Plant samples were

Table 1. List of the 27 taxa in industrial complex area, the families to which they belong and their habit

Taxon	Abbreviation	Family	Habit
Ginkgo biloba	*Gb*	Ginkgoaceae	DCT
Cedrus deodara	*Cd*	Pinaceae	ECT
Pinus densiflora	*Pd*	Pinaceae	ECT
Metasequoia glyptostroboids	*Mg*	Taxodiaceae	DCT
Chamaecyparis obtusa	*Co*	Cupressaceae	ECT
Juniperus chinensis	*Jc*	Cupressaceae	ECT
Populus euramericana	*Pe*	Salicaceae	DBT
Salix pseudo-lasiogyne	*Sp*	Salicaceae	DBT
Platycarya strobilacea	*Ps*	Juglandaceae	DBT
Castanopsis cuspidata var. sieboldii	*Cc*	Fagaceae	EBT
Quercus palustris	*Qp*	Fagaceae	DBT
Zelkova serrata	*Zs*	Ulmaceae	DBT
Celtis sinensis	*Cs*	Ulmaceae	DBT
Liriodendron tulipifera	*Lt*	Magnoliaceae	DBT
Machilus thunbergii	*Mt*	Lauraceae	EBT
Platanus occidentalis	*Po*	Platanaceae	DBT
Prunus yedoensis	*Py*	Rosaceae	DBT
Sophora japonica	*Sj*	Leguminosae	DBT
Robinia pseudo-acacia	*Ra*	Leguminosae	DBT
Acer buergerianum	*Ab*	Aceraceae	DBT
Aesculus turbinata	*At*	Hippocastanaceae	DBT
Hibiscus syriacus	*Hs*	Malvaceae	DBS
Firmiana simplex	*Fs*	Sterculiaceae	DBT
Lagerstroemia indica	*Li*	Lythraceae	DBT
Chionanthus retusa	*Cr*	Oleaceae	DBT
Ligustrum japonicum	*Lj*	Oleaceae	EBS
Viburnum awabuki	Va	Caprifoliaceae	DBT

*DBT, DBS, DCT, EBT, EBS and ECT correspond to deciduous broad-leaf trees, deciduous broad-leaf shrubs, deciduous coniferous trees, evergreen broad-leaf trees, evergreen broad-leaf shrubs and evergreen coniferous trees respectively.

collected during August, 2005. Collected leaf samples were carried to the laboratory in portable freezers (4°C). Samples were collected from at least five different individuals. Half of each material was kept in nylon bags at -70°C and another half was freeze dried.

2.2. Antioxidant capacity

Antioxidant capacity was expressed by DPPH radical scavenging ability. Three grams of the ground power were mixed with 50 mL of methanol and placed in a shaking incubator for 24 h at 25°C. The macerated mixture was filtered and centrifuged (5 min, 395×g). The remaining residue was extracted again with water sequentially following the above extraction procedure.

This assay was based on the scavenging of stable 1,1-diphenyl-2-picrylhydrazyl (DPPH) radicals by the radical scavenging components in water extracts. Modified method of Brand-Williams (1995) was used to investigate the free radical scavenging activity. DPPH solution in dimethyl sulfoxide (DMSO) was prepared at the concentration of 300 mM. A 2 mL fraction of extract and 2 mL of fresh prepared DPPH solution were thoroughly mixed. The reaction mixture was incubated for 1h and centrifuged (5 min, 222×g). Absorbance of the supernatant was measured at 517 nm using UV-VIS spectrophotometer (Shimadzu, Japan).

2.3. Lipid peroxidation

Lipid peroxidation was determined by measuring the amount of malondialdehyde (MDA) produced by the thiobarbituric acid reaction as described by Heath and Packer (1968). The crude extract was mixed with the same volume of a 0.5% (w/v) thiobarbituric acid solution containing 20% (w/v) trichloroacetic acid. The mixture was heated at 95°C for 30 min and then quickly cooled in an ice-bath. The mixture was centrifuged at 3000×g for 10 min and the absorbance of the supernatant was monitored at 532 and 600 nm. After

subtracting the non-specific absorbance (600 nm), the MDA concentration was determined by its molar extinction coefficient (155 mM^{-1} cm^{-1}) and the results expressed as μmol MDA g^{-1} FW.

2.4. Antioxidant enzyme activities

Fresh leaves (0.1g) were homogenized under ice-cold condition with 5 mL of 50 mM phosphate buffer (pH 7.0), 10 mM ascorbic acid (AsA) and 1.0% (w/v) polyvinylpyrrolidone. The homogenate was centrifuged at 20,000×g for 30 min, and the supernatant was collected for enzyme assays. SOD was assayed based on the inhibition of reduction of nitro-blue tetrazolium in the presence of xanthine at 530 nm according to the method of Beauchamp and Fridovich (1971). Activity of GR was assayed as described in Carlberg and Mannervik (1985). The assay was carried out in a reaction mixture containing 50 mM phosphate buffer (pH 7.8), 0.1 mM NADPH, 0.5 mM GSSH and 0.1 mL enzyme extract. The change in A340 was recorded for 5min after the addition of enzyme extract. CAT activity was determined by following a two-step procedure (Fossati *et al.*, 1980). The rate of dismutation of H_2O_2 to water and molecular oxygen is proportional to the concentration of catalase. Therefore, the sample containing catalase was incubated in the presence of a known concentration of H_2O_2. After incubation for exactly one minute, the reaction was quenched with sodium azide. The amount of H_2O_2 remaining in the reaction mixture was then determined by the oxidative coupling reaction of 4-aminophenazone (4-aminoantipyrene) and 3,5-dichloro-2-hydroxybenzenesulfonic acid (DHBS) in the presence of H_2O_2 and catalyzed by horseradish peroxidase (HRP). The resulting quinoneimine dye was measured at 520 nm. All the activities of enzyme were measured using UV-120 (Shimadzu, Japan).

2.5. Determination of nitrogen content

Nitrogen content was measured using an elemental analyzer (FlashEA 1112 elemental analyzer, Thermo electron corporation, USA). Collected samples were dried at 85°C for 48 hrs, and then it were homogenized by grinding. Two to five milligram of samples were oxidized at 1800°C for five seconds in reactor with oxygen, and oxidized gases flowed with helium gas as carrier through copper for reducing. Reduced gases were separated by gas chromatographic column and detected by thermal conductivity detector (TCD). Thermal conductivity detector read thermal different value occurred by electrical resistance discrepancy between pure helium carrier gas (reference) and eluted gas (carrier gas and sample).

III. RESULTS AND DISCUSSION

3.1. Antioxidant capacity and lipid peroxidation

Fig. 1 shows the antioxidant capacity as a DPPH radical scavenging ability, and lipid peroxidation levels expressed MDA content of each taxon of roadside trees in industrial complex area. All data obtained in the present study are the means of five individuals with standard deviation.

Among 27 taxa, the highest value of antioxidant capacity was given by *Cedrus deodara* (91.4%). The lowest was by *Firmiana simplex* (56.9%). Thus, the antioxidant capacity differed by a factor of 1.61 between the highest and the lowest (Fig. 1). We have previously reported a very similar result that the difference between the highest one and the lowest one of 14 coniferous trees under natural condition was more than 1.4-fold (Han *et al.*, 2006). The genetic and/or physiological cause for this difference in the antioxidant capacity remains unclear although it is a vital and intriguing subject in phytoremediation of this air pollution (Morikawa *et al.*, 2003).

At lipid peroxidation level, little amount of MDA was observed in *Lagerstroemia indica* and *Ginkgo biloba*, and their MDA contents were 6.6 μmol g^{-1} and 8.0 μmol g^{-1}, respectively. In addition to *Platanus occidentalis*, *Castanoposis cuspidata* var. *sieboldii*, *Machilus thunbergii* and *Juniperus chinensis* showed high MDA content (Fig. 1). Conceivably, their lipid peroxidation levels were results of inhibition or suppression by air pollutants. In fact, the needles of *J. chinensis* were deteriorated and died at their growing area. On the other hand, *G. biloba*, *C. deodara*, *Pinus densiflora*, *Metasequoia glyptostroboides*, *Chamaecyparis obtusa*, *Platycarya strobilacea*, *L. indica* showed high antioxidant capacity and low lipid peroxidation level (Fig. 1). They are considered to be equipped with "all necessary apparatuses" so that they can express high resistance against environmental stress.

3.2. Families of high antioxidant capacity and low lipid peroxidation

C. deodara, showing the highest species in the antioxidant capacity, belongs to the Pinaceae family. *P. strobilacea*, *P. densiflora* and *G. biloba* which belong to

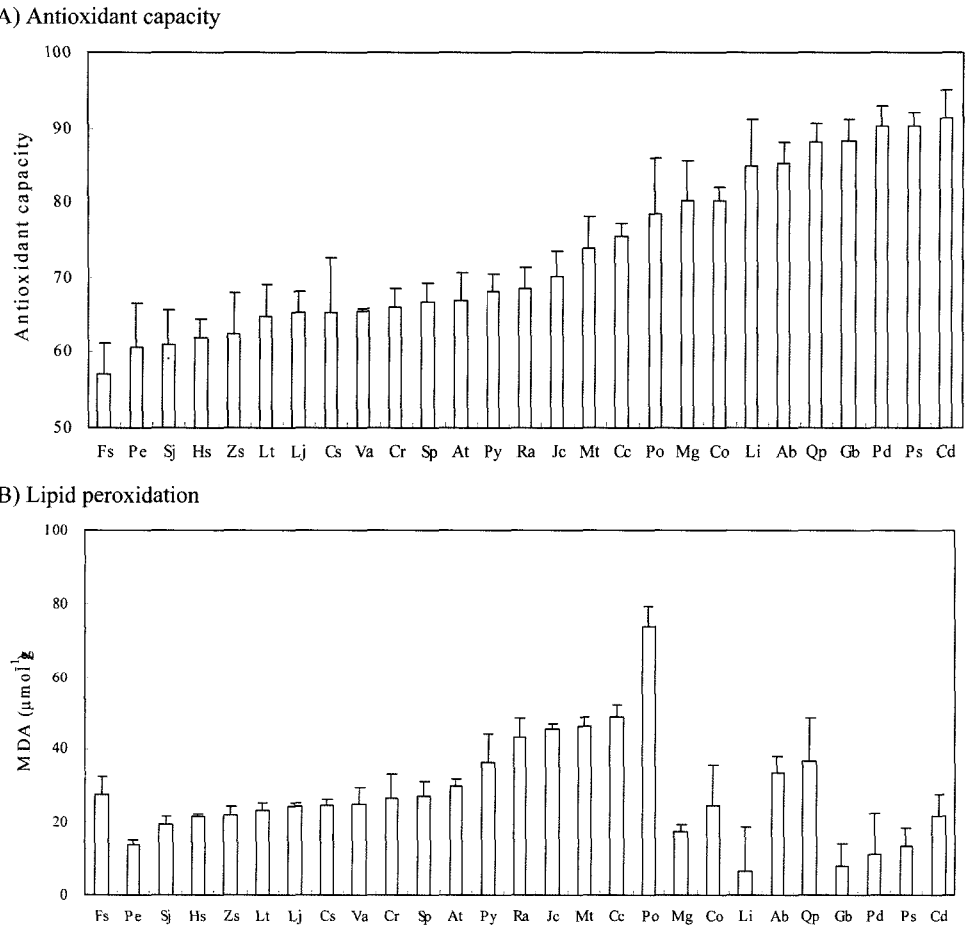

Fig. 1. Antioxidant capacity (above) as a DPPH radical scavenging rate and lipid peroxidation level (below) of 27 roadside trees in industrial complex area. Each bar represents mean values and standard deviations of five individuals (antioxidant capacity P=0.0001***, lipid peroxidation level P=0.0001***, ***significant at P≤0.001).

the Juglandaceae, Pinaceae and Ginkgoaceae respectively had high antioxidant capacity. Moreover since they showed low lipid peroxidation level, these families are the best source of roadside trees against atmospheric pollutants. Meanwhile, although *Quercus palustris* (88.1%, 5th) in Fagaceae family and *Acer buergerianum* (85.3%, 6th) in Aceraceae family had high antioxidant capacity, their high lipid peroxidation level showed low resistance against air pollutants. Takahashi *et al.*(2005) reported that Leguminosae, Salicaceae, and Myrtaceae families are a good source of roadside trees of high NO_2 assimilation and high resistance to NO_2. In our study, however, both *Sophora japonica* and *Robinia pseudo-acacia* belonging to Leguminosae family had low antioxidant capacity and specially *R. pseudo-acacia* represented high lipid peroxidation level. In addition, both *Populus euramericana* and *Salix pseudo-lasiogyne* belonging to Salicaceae showed low antioxidant capacity and *S. pseudo-lasiogyne* had high lipid peroxidation level. Therefore they are not a good source of roadside trees for phytoremediation unlike the results of Takahashi *et al.* (2005).

3.3. Deciduous versus evergreen woody plants

The 27 taxa of woody plants include 7 evergreen woody plants consisting of 2 broad-leaf trees, 1 broad-leaf shrub and 4 coniferous trees, and 20 deciduous woody plants consisting of 1 broad-leaf shrub, 17 broad-leaf trees and 2 coniferous trees. Their antioxidant capacity and lipid peroxidation level are depicted in Fig. 2.

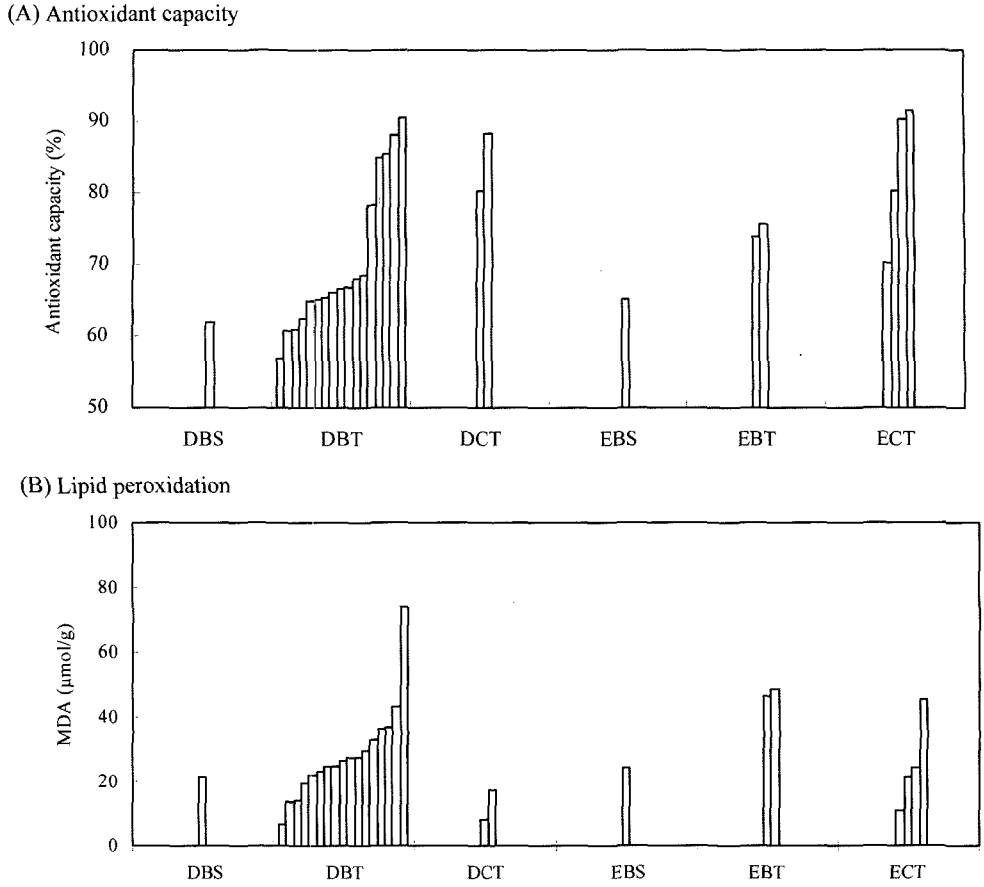

Fig. 2. Antioxidant capacity (above) and lipid peroxidation level (below) on 6 habits of 27 roadside trees in industrial complex area.

In comparing antioxidant capacity between 7 evergreen woody plants and 20 deciduous ones, *C. deodora*, and *P. densiflora* of the evergreen woody plants had distinctly higher antioxidant capacity than any of the 19 deciduous woody plants, except for *P. strobilacea* (see Fig. 2). But deciduous woody plants were included six species that had distinctly lower antioxidant capacity than any of 7 evergreen woody plants.

In comparing lipid peroxidation level, *L. indica* and *G. biloba* of the deciduous woody plants had distinctly lower lipid peroxidation level than any of the 7 evergreen woody plants (see Fig. 2). Among 20 deciduous woody plants, *P. occidentalis* was only species that had higher lipid peroxidation than any of 7 evergreen ones.

As the result, the average value (72.2%) of antioxidant capacity of the deciduous woody plants was not significantly different in comparison with that (74.3%) of the evergreen ones. But the average value (20.9 μmol g^{-1}) of MDA content of the deciduous woody plants was lower than that (32.5 μmol g^{-1}) of the evergreen ones as indicated in Fig. 2. Low lipid peroxidation of deciduous woody plants results from the features of high net photosynthesis (Mooney and Gulmon, 1982; Reich *et al.*, 1997) and high relative growth rate (Reich *et al.*, 1997), whereas high lipid peroxidation level of evergreen ones reflects on MDA accumulation in the needle under long-term exposing condition of air pollutants.

3.4. Classification, enzyme activities and nitrogen content

It is not likely to that plants have always a negative correlation between antioxidant capacity and lipid peroxidation in their systems. That is, lipid peroxidation is not always low since antioxidant capacity is high. These results may be related to plant tolerance or sen-

Table 2. Classification of the 27 roadside trees into four types based on antioxidant capacity and lipid peroxidation level

Type	I	II	III	IV
Taxon	*G. biloba* *C. deodara* *P. densiflora* *M. glyptostroboides* *C. obtusa* *P. strobilacea* *L. indica*	*J. chinensis* *C. cuspidata* var. *sieboldii* *Q. palustris* *M. thunbergii* *P. occidentalis* *A. buergerianum*	*P. euramericana* *Z. serrata* *C. sinensis* *L. tulipifera* *S. japonica* *H. syriacus* *L. japonicum* V. awabuki	*S. psudo-lasiogyme* *P. yedoensis* *R. pseudo-acacia* *A. turbinata* *F. simplex* *C. retusa*

First type (I) - high antioxidant capacity and low lipid peroxidation, second type (II) - high antioxidant capacity and high lipid peroxidation, third type (III) - low antioxidant capacity and low lipid peroxidation, fourth type (IV) - low antioxidant capacity and high lipid peroxidation

Table 3. Differences of antioxidant enzyme activities and nitrogen contents in the leaves of 27 roadside trees in industrial complex area

Taxon	SOD (unit g^{-1})	GR (nmol g^{-1})	CAT (unit g^{-1})	nitrogen (%)
Ginkgo biloba	970±855^{bc}	349±61^{gh}	363±16^{fg}	1.44±0.13^{klm}
Cedrus deodara	308±195^{c}	359±44^{fgh}	346±24^{g}	1.17±0.21^{mn}
Pinus densiflora	3500±819^{bc}	331±62^{gh}	370±10^{efg}	1.41±0.09^{klm}
Metasequoia glyptostroboides	6798±3669^{bc}	269±25^{h}	364±22^{fg}	2.59±0.26^{bcd}
Chamaecyparis obtusa	3665±913^{bc}	397±154^{defgh}	359±11^{fg}	1.33±0.14^{klm}
Juniperus chinensis	2125±281^{bc}	534±94^{bcd}	377±19^{efg}	1.26±0.07^{lmn}
Populus euramericana	4990±503^{bc}	605±115^{ab}	475±136^{bcd}	2.47±0.32^{cde}
Salix pseudo-lasiogyne	3211±252^{bc}	532±91b^{cd}	433±51^{def}	2.73±0.12^{bc}
Platycarya strobilacea	6089±347^{bc}	431±73^{cdefg}	371±43^{efg}	2.45±0.25^{cde}
Castanopsis cuspidata var. *sieboldii*	40143±20126^{a}	373±170^{cdefg}	626±82^{a}	1.34±0.06^{klm}
Quercus palustris	9019±3809^{b}	452±72^{cdefg}	413±41^{defg}	1.77±0.09^{hij}
Zelkova serrata	5524±1247^{bc}	491±157^{bcdef}	411±72^{defg}	2.02±0.35^{fgh}
Celtis sinensis	5120±824^{bc}	501±116^{bcde}	477±102^{bcd}	2.71±0.15^{bcd}
Liriodendron tulipifera	7043±579^{bc}	427±92^{cdefg}	451±35^{cde}	2.26±0.33^{ef}
Machilus thunbergii	6628±572^{bc}	455±124^{cdefg}	441±73^{cdef}	1.21±0.25^{mn}
Platanus occidentalis	5971±1411^{bc}	421±57^{cdefg}	402±47^{defg}	1.97±0.28^{gh}
Prunus yedoensis	2251±849^{bc}	370±72^{efgh}	365±31^{fg}	1.81±0.22^{hi}
Sophora japonica	2757±872^{bc}	449±81^{cdefg}	431±46^{defg}	2.77±0.16^{b}
Robinia pseudo-acacia	4034±1496^{bc}	381±65^{efgh}	388±35^{efg}	3.18±0.13^{a}
Acer buergerianum	37050±4599^{a}	691±140^{a}	533±47^{b}	1.53±0.16^{jkl}
Aesculus turbinata	553±219^{bc}	382±103^{efgh}	357±22^{fg}	1.57±0.22^{ijk}
Hibiscus syriacus	2144±641^{bc}	436±111^{cdefg}	411±34^{defg}	2.42±0.19^{de}
Firmiana simplex	9828±1600^{bc}	558±75^{bc}	515±45^{bc}	2.66±0.28^{bcd}
Lagerstroemia indica	39329±11579^{a}	137±53^{i}	420±42^{defg}	1.26±0.03^{lmn}
Chionanthus retusa	1785±582^{bc}	355±56^{fgh}	431±23^{defg}	1.89±0.34^{gh}
Ligustrum japonicum	3378±1708^{bc}	407±31^{defg}	474±100^{bcd}	0.99±0.09^{n}
Viburnum awabuki	2694±599^{bc}	460±57^{cdefg}	421±54^{defg}	2.12±0.10^{fg}
Pr > F	0.0001***	0.0001***	0.0001***	0.0001***

Each data represents mean values and standard deviations of five individuals. The same letters are not significantly different at 5% level in Duncan's multiple range test. ***Significant at P≤0.001.

sitivity against stress, the efficiency of antioxidant function and the balance of each antioxidant systems. Thus tree species that have high tolerance, antioxidant efficiency and good balance of all antioxidant systems control lipid peroxidation rate with their antioxidant activity, but tree species that are sensitive against stress and have low antioxidant efficiency and independent antioxidant systems do not represent the correlation

between antioxidant capacity and lipid peroxidation rate. Han *et al.* (2006) reported that antioxidant systems differed among species and were developed suitably according to tree species.

Based on the above mentioned criteria, the 27 taxa of woody plants can be classified into the following four types: the first type-those of high antioxidant capacity and low lipid peroxidation, second type-those of high antioxidant capacity and high lipid peroxidation, third type-those of low antioxidant capacity and low lipid peroxidation, fourth type-those of low antioxidant capacity and high lipid peroxidation. The first types represent resistance or tolerance against pollutants, but the fourth types represent sensitive responses under pollutant exposure. The taxa included in these types are 7 (first type), 6 (second one), 8 (third one) and 6 (fourth one) taxa (Table 2).

In Table 3, among 7 first types, *L. indica* and *M. glyptostroboides* showed high SOD activity and low GR and CAT activity. SOD activity of *L. indica* was 39329 unit g^{-1} (2nd) and that of *M. glyptostroboides* was 6798 unit g^{-1} (7th). However *C. cuspidata* var. *sieboldii* and *A. buergerianum* which belong to second type represented high activity at two or three enzymes. *C. cuspidata* var. *sieboldii* represented the highest activity for SOD (40143 unit g^{-1}, 1st) and CAT (626 unit g^{-1}, 1st) among 27 taxa, and *A. buergerianum* showed high activity for SOD (37050 unit g^{-1}, 3rd), GR (691 nmol g^{-1}, 1st) and CAT (533 unit g^{-1}, 2nd). Meanwhile *F. simplex* included into fourth types represented high antioxidative activity, and their SOD, GR and CAT activity were 9828 unit g^{-1} (4th), 558 nmol g^{-1} (3rd) and 515 unit g^{-1} (3rd) respectively. But SOD, GR and CAT of *P. yedoensis*, *R. pseudo-acacia*, *A. turbinata* and *C. retusa* represented very low activity. Their SOD activities were 2251unit g^{-1} (21th), 4034 unit g^{-1} (14th), 553 unit g^{-1} (26th) and 1785 unit g^{-1} (24th), and GR activities were 370 nmol g^{-1} (21st), 381 nmol g^{-1} (19th), 382 nmol g^{-1} (18th) and 355 nmol g^{-1} (23rd). In addition, CAT activities were 365 unit g^{-1} (22nd), 388 unit g^{-1} (18th), 357 unit g^{-1} (26th) and 431 unit g^{-1} (11th) respectively.

In addition, most of the first or second type species which have high antioxidant capacity represented low nitrogen content in their leaves. However third or forth type species which have low antioxidant capacity showed high nitrogen content in their leaves. Takahashi *et al.* (2005) reported that *R. pseudo-acacia*, *Hibiscus* sp., *Zelkova serrata* and *Viburnum awabuki* had high NO_2 assimilation capacity but low resistance to NO_2. On the contrary, *M. glyptostroboides*, *Acer buergerianum*, *Quercus crispula*, *Platanus* sp. and *Juniperus chinensis* var. *sargentii* had low NO_2 assimilation but high resistance to NO_2. In our results, however, *M. glyptostroboides*, *P. strobilacra* and *P. occidentalis* which belong to first or second type had extraordinary high antioxidant capacity and high nitrogen content. Therefore three species are considered as a good phytoremediators in industrial complex areas. In future, the negative relations between antioxidant capacity and nitrogen content have to be elucidated through the more researches.

적 요

대기오염물질을 정화하기에 적합한 수종을 탐색하기 위하여, 공단지역의 가로수로 식재된 27개 수종의 잎에서 항산화 능력, 과산화 지질 함량 및 질소함량을 조사하였다. 27개 수종 중 항산화 능력이 가장 높은 수종은 개잎갈나무(91.4%) 이었고, 가장 낮은 수종은 벽오동(56.9%) 이었다. MDA 함량이 가장 적은 수종은 배롱나무와 은행나무였으나, 양버즘나무, 구실잣밤나무, 후박나무 및 향나무에서는 높은 MDA 함량이 측정되었다. 낙엽활엽수의 항산화 능력은 상록수의 항산화 능력과 뚜렷한 차이가 없었으나, 낙엽활엽수의 MDA 함량은 상록수의 MDA 함량보다 낮게 나타났다. 27개 수종은 항산화 능력과 과산화지질 함량을 기준으로 하여 다음과 같이 4개의 범주로 구분하였다. 범주 I은 높은 항산화 능력과 낮은 과산화지질 함량을 가진 수종, 범주 II는 높은 항산화 능력과 높은 과산화지질 함량을 가진 수종, 범주 III은 낮은 항산화 능력과 낮은 과산화지질 함량을 가진 수종, 범주 IV는 낮은 항산화 능력과 높은 과산화지질 함량을 가진 수종. 이들 4개 범주에 속하는 수종은 각각 7종(범주 I), 6종(범주 II), 8종(범주 3), 6종(범주 IV) 이었다. 높은 항산화 능력을 가진 범주 I과 II의 수종들은 낮은 질소함량을 나타냈으나, 낮은 항산화능력을 가진 범주 III과 IV의 수종들은 높은 질소함량을 나타냈다. 그러나 범주 I과 II에 속하는 메타세코이아, 굴피나무, 양버즘나무는 예외적으로 높은 항산화 능력과 높은 질소함량을 나타냄으로써 이들 수종들은 공단지역의 식재 수종으로 적합한 것으로 판단되었다.

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