

Research article

Rose cultivars for biomonitoring of air quality

Wanjala Sylvia Nafula^a, László Orlóci^b, Szilvia Kisvarga^b, Gábor Boronkay^b,
Béla Tóthmérész^{a,c}, Stewart Ajele^a, Vanda Éva Abriha-Molnár^{a,d,*}, Edina Simon^{a,d}

^a Department of Ecology, University of Debrecen, H-4032 Debrecen, Hungary

^b Ornamental Plant and Green System Management Research Group, Institute of Landscape Architecture, Urban Planning and Garden Art, Hungarian University of Agriculture and Life Sciences, H-1223 Budapest, Hungary

^c MTA-DE Biodiversity and Ecosystem Services Research Group, H-4032 Debrecen, Hungary

^d HUN-REN-UD Anthropocene Ecology Research Group, H-4032 Debrecen, Hungary



ARTICLE INFO

Keywords:

Air pollution
Ascorbic acid
Bioindication
Chlorophyll
NO_x
SO₂
Urbanisation

ABSTRACT

The usefulness of rose cultivars for air quality monitoring was assessed; the assessment is based on the Air Pollution Tolerance Index and the Air Quality Index. A total of 11 cultivars of roses were evaluated; they were collected from a peri-urban area of the city of Budapest (Hungary). The Air Pollution Tolerance Index is based on the physiological and biochemical parameters of the specimens, including the relative water content, leaf pH, ascorbic acid, and total chlorophyll. The Air Quality Index is based on the concentration of particulate matter, NO_x, and SO₂. We found that the Air Pollution Tolerance Index values of the selected rose cultivars ranged between 6.8 and 10.5, suggesting that these rose cultivars are sensitive indicators of air pollution. Significant differences were found among the cultivars based on the concentration of ascorbic acid, total chlorophyll, and relative water content. Seasonal differences were found in the Air Quality Index; a significantly higher value was found in autumn, and significant differences were also found among seasons based on the air pollutants. Our findings suggest that the studied rose cultivars are useful indicators of air pollution. Planting rose cultivars in urban green spaces alongside established species that are tolerant to polluted air provides a good opportunity for bioindication. Besides their aesthetic value, these plants may prove to be useful in urban greening projects.

1. Introduction

Air pollution is a major environmental problem, and it is responsible for one in every nine deaths annually in many urban areas and regions surrounding industrial sites [1]. Plants are vital to decreasing air pollution in densely populated areas. Air pollutants may cause damage to leaves and decrease photosynthetic activity. Thus, the identification and/or categorisation of plant species according to their sensitivity and/or tolerance to air pollution is important because plants can serve as bioindicators of air pollution and as sinks for air pollutants in urban and industrial habitats [2]. The sensitivity of plants varies substantially among species, subspecies, and varieties. This sensitivity is also influenced by environmental factors such as the water status, light, relative humidity, ambient temperature, and nutrient availability, among others.

The sensitivity and tolerance responses were categorised by Singh et al. [3] based on the Air Pollution Tolerance Index (APTI), which is generally used to study the sensitivity of species to air pollution and important parameters [2,4,5,6]. The APTI is based on four

* Corresponding author. Department of Ecology, University of Debrecen, H-4032 Debrecen, Hungary.
E-mail address: molnarvandaeva@science.unideb.hu (V.É. Abriha-Molnár).

<https://doi.org/10.1016/j.heliyon.2025.e41978>

Received 4 November 2024; Received in revised form 14 January 2025; Accepted 14 January 2025

Available online 15 January 2025

2405-8440/© 2025 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

biological parameters of the plants: the total chlorophyll content of the leaf (TChl), the pH of the plant leaf extract, and the relative water content (RWC) and ascorbic acid content (AAC) of plants. The slow depletion of chlorophyll and accompanying yellowing of leaves, which may be related to a resulting reduction in the ability to perform photosynthesis, are some of the most frequent effects of air pollution on plants [7,8]. Chlorophyll is a light-driven photoreceptor that enables the fixation of carbon dioxide and oxygen and plays a crucial part in the photosynthetic process [9]. Among air pollutants, sulphur oxides are the most common pollutants that are likely to cause these chlorophyll reduction effects in plants because of their high solubility compared to carbon (IV) oxide and oxygen gases [10]. A study by Swanepoel et al. [11] reported that the exposure of a soy plant (bio-indicator) to sulphur dioxide fumigation caused discolouration, curling, and the suppression of carbon dioxide uptake. Sharma and Tripathi [12] reported significant variations in the amounts of pigments (chlorophyll *a*, chlorophyll *b*, and carotenoids), ascorbic acid, sugar, and sulphate-sulphur in plants exposed to thermal power emissions. Their results indicated that chlorophyll *a*, chlorophyll *b*, and carotenoids decreased with pollution, while the AAC showed a positive correlation with pollution.

Air pollutants have also been reported to be potential causes of changes in the pH levels of plants. Acidic gases such as CO₂, SO₂, and NO₂ can react with water to form the anionic species HCO₃⁻, SO₃²⁻, and NO_x, which can then produce H⁺ [10]. Hydrogen ions are responsible for altering the pH level of plants. Acidic air pollutants can potentially decrease pH levels in plants. Studies [13,14] evaluating the biochemical parameters of plants growing in polluted environments reported a significant decrease in the pH levels of the sample plants compared to the control experiments. High pH levels in leaves increase the effectiveness of converting hexose sugar to ascorbic acid. Ascorbic acid has antioxidant properties, which protect plants against oxidative damage [15]. In our study, the tolerance levels of 11 rose cultivars were evaluated in order to assess their suitability for use in the biomonitoring of air quality. In addition, the seasonal Air Quality Index was also calculated in order to assess the temporal variability of the air quality. The research was carried out in Budapest, Hungary, in 2023. To the best of the author's knowledge, *Rosa* sp. plants are rarely studied as bio-indicators, and the rose cultivars selected here have not been previously assessed in Hungary.

2. Material and methods

2.1. Sample collection

Samples were collected in the peri-urban area of the city of Budapest; this region of the city is a busy area with heavy traffic. There is a collection of rose varieties here that serves as a gene bank, holding an invaluable collection of rose varieties and cultivars. It was established in 1964–1965 by the former Horticultural Research Institute. Today, there are 7000–8000 rose cultivars, making it the largest collection in Hungary. The rose samples were collected in September 2022. Each cultivar was sampled in triplicate, with one repetition including at least five green, mature leaflets, characteristic of that cultivar.

2.2. Studied rose cultivars

There are over 30,000 different varieties of roses, some of which are indigenous to Asia, Europe, North America, and Africa [16]. These varieties are bred over time as a result of hybridisation and polyploidisation. Humans have influenced their reproduction by raising some of them and leaving others to exist in a semi-wild state. The rose cultivars that were studied are listed in Table 1 and are referred to as Cultivars 1 to 11.

2.3. Air Pollution Tolerance Index (APTI)

The procedure described by Molnár et al. [17] and Simon et al. [18] was followed for the determination of the AAC (*A*), the TChl (*T*), the pH of the leaf extract (*P*), and the RWC (*R*). Using these parameters, the equation proposed by Singh et al. [3] was applied to calculate the APTI (Eq. (1)):

$$APTI = [A \times (T + P) + R] / 10 \quad (1)$$

Table 1
The names of the rose cultivars.

	Registration name	Groups
Cultivar 01	<i>Rosa canina</i> L. 'Inermis 8a1-5 C2000' ^a	Canina
Cultivar 02	<i>Rosa</i> × <i>damascena</i> Mill. La Quatre Saisons Continue	Damask
Cultivar 03	<i>Rosa</i> × <i>hybrida</i> hort. 'Báthory István emléke' ^a	Floribunda
Cultivar 04	<i>Rosa gallica</i> L. Conditorum	Gallica
Cultivar 05	<i>Rosa</i> × <i>hybrida</i> hort. 'Munkács' ^a	Floribunda
Cultivar 06	<i>Rosa</i> × <i>hybrida</i> hort. 'Nagy Imre emléke' ^a	Hybrid tea
Cultivar 07	<i>Rosa gallica</i> L. Officinalis	Gallica
Cultivar 08	<i>Rosa</i> × <i>hybrida</i> hort. Peace	Hybrid tea
Cultivar 09	<i>Rosa</i> × <i>hybrida</i> hort. Korgeleflo	Ground Cover
Cultivar 10	<i>Rosa</i> × <i>hybrida</i> hort. St. Elizabeth of Hungary	Shrub
Cultivar 11	<i>Rosa</i> × <i>hybrida</i> hort. Taboo	Hybrid tea

^a These cultivars have no registration names, only commercial names.

The categorisation of the *Rosa* cultivars based on APTI values is as follows: APTI >20, tolerant; APTI = 17–20, moderately tolerant; APTI = 13–16, intermediate; and APTI ≤12, sensitive [3].

2.4. Air Quality Index (AQI)

The Air Quality Index (AQI) was calculated using Eq. (2) [19], where the actual concentrations of each air pollutant are compared with the corresponding standard concentration (denoted by the prefix ‘S’). Air pollutant data were collected from the Hungarian Meteorological Service web page (<https://legszenyezetseg.met.hu/en>) [20]. For the calculation of the AQI value, the threshold limit of European air quality was used (https://environment.ec.europa.eu/topics/air/air-quality/eu-air-quality-standards_en) [21]:

$$AQI = 1 / 3 (SO_2 / S_{SO_2} + NO_x / S_{NO_x} + SPM / S_{SPM}) \times 100 \quad (2)$$

The categorisation of the air quality based on AQI values is as follows: 0–25: clean air (CA), 26–50: light air pollution (LAP), 51–75: moderate air pollution (MAP), 76–100: heavy air pollution (HAP), and >100: severe air pollution (SAP).

2.5. Data analysis

The SPSS version 21.0 program package was used during the statistical analyses. The homogeneity of variances was tested with Levene’s test. The differences among rose cultivars and seasons for AQI values were tested using analysis of variance (ANOVA). When ANOVA provided significant differences, Tukey’s test was used for pairwise comparison among the groups. The Pearson correlation was used to study the correlation between the studied parameters and air pollutant concentration.

3. Results and discussion

3.1. APTI and its parameters

Based on the APTI values, our results demonstrated that all the studied rose cultivars are sensitive to air pollution (Fig. 1). A significantly higher APTI value was found for Cultivar 01 than for the other cultivars ($F = 7.144$; $p < 0.001$). We found that the APTI values of the selected rose cultivars ranged between 6.8 and 10.5, suggesting that these rose cultivars are sensitive to air pollution.

Several studies evaluated the APTI of plants exposed to air pollution [13,17,18,22]. In a study in Hyderabad, India, the APTI values of 16 distinct plant species were studied; these plant species were grown in a variety of settings, including residential, busy, industrial, and peri-urban areas [23]. The plant species were divided into four categories based on the tolerance index value: sensitive, tolerant, moderately tolerant, and tolerant plant species. In another study [13], the APTI was studied in 12 plant species, wherein samples were collected from the polluted site, and the unpolluted plant species (control) were collected from the botanical garden. The results showed that plants collected from the polluted area had higher APTI values than those collected from the unpolluted area. Different plants possessed different APTI values, indicating that different plants respond differently to pollution and possess different tolerance capacities. A similar study [17] compared the APTI values of two plant species, *Celtis occidentalis* and *Tilia* sp., in Debrecen, Hungary. The study reported high APTI values in species collected from polluted environments compared to the control habitats. The values also

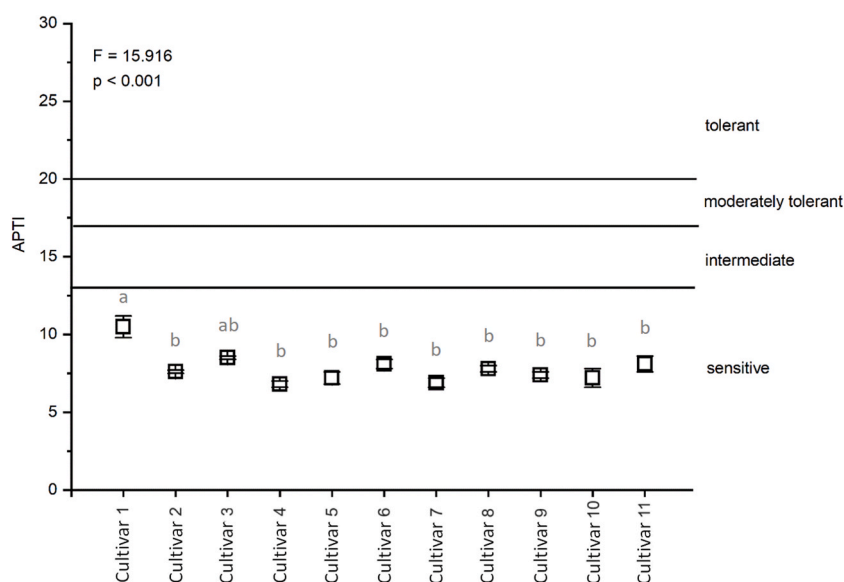


Fig. 1. APTI values (mean ± SD) for the studied rose cultivars. Means marked with a common letter are not significantly different.

varied given the nature of the land use (i.e. urban and industrial). APTI values also tend to have a positive correlation with the increase in population. Despite the high air pollution levels in urban areas, there is a desire to have a green surrounding environment. Urban planners and developers consider the APTI to be a very crucial tool for decision-making when it comes to identifying tolerant plants to grow in such environments [17]. APTI evaluation in plants can also be used to gauge the levels of air pollution. For example, Bharti et al. [24] conducted a study evaluating the APTI levels in 25 plant species collected in the Talkatora Industrial Area, Lucknow Uttar Pradesh, in India. The APTI values varied significantly, and the study suggested that plant species that were found to have APTI values < 11 (sensitive) can be used as indicators for pollution, while those with APTI values ≥ 17 can be selected to maintain a green environment in industrial areas. It is worth mentioning that, in addition to the APTI method, the binding of contaminants (e.g. particulate matter) on the leaf surface could provide a more comprehensive insight into the role of plants in biomonitoring. Overall, a limiting factor to using plant species as bioindicators is the seasonal foliage loss. Most roses are deciduous, so sampling the leaves may not be possible at all times of the year.

We observed significant differences among the study cultivars based on the AAC ($F = 11.807$, $P < 0.001$) (Fig. 2), TChl ($F = 4.488$, $P = 0.002$) (Fig. 3), and RWC ($F = 3.489$, $P = 0.007$) (Fig. 4) of *Rosa* leaves.

Variances in the AAC ranged between 0.60 ± 0.03 and 3.29 ± 1.39 . Cultivar 01 had the maximum AAC and Cultivar 10 had the minimum AAC (Fig. 2). The AAC is one of the most prevalent water-soluble antioxidants in plants and acts as a significant redox buffer to govern a number of physiological processes, including growth, development, and stress [25]. Chloroplasts normally produce reactive oxygen species (ROS) as a byproduct of the cellular metabolism; however, stressors such as pollution cause production to rise, causing oxidative damage [26]. Hydrogen peroxide (H_2O_2), superoxide, and hydroxyl are examples of ROS that are released by plants [15]. Ascorbic acid, given its antioxidant properties, protects plants against oxidative stresses. Plants with higher AAC levels therefore stand a better chance of being protected against oxidative damage, hence turning out to be tolerant, while plants with low AAC levels are prone to oxidative damage, hence becoming sensitive. One study [27] reported a decrease in the AACs of plants in polluted environments; plants that maintained a high AAC in polluted environments were considered tolerant, while those with low AACs were considered sensitive to pollution. In this study, Cultivar 01 exhibited a maximum AAC of 3.288 mg g^{-1} , which reflects its relatively high tolerance compared to all other sample cultivars.

In this study, the TChl values ranged between 0.9 ± 0.1 and $3.3 \pm 0.3 \text{ mg g}^{-1}$. The maximum and minimum TChl values were observed in Cultivar 01 and Cultivar 04, respectively (Fig. 3). There was a significant difference among the TChl values of the samples ($p = 0.002$). The TChl is subject to a variety of photochemical processes, including bleaching and reversible oxidation [9]. Plants release ROS in the chloroplast in response to environmental stressors, such as air pollution, which can damage the cell structures and lower the content of total chlorophyll [28]. Moreover, pollutants permeate the leaves through the stomata, altering the chloroplast and causing a decrease in the pigment responsible for photosynthetic activity. A plant's overall growth and development are therefore impacted by changes in the total amount of chlorophyll.

The results of this study demonstrated that the RWCs of the sampled rose cultivars were very closely related, ranging between 61 ± 1 and 79 ± 1 (Fig. 4). Cultivar 04 had the lowest RWC, while Cultivar 03 had the highest RWC. Environmental stresses are known to affect the plants' growth and/or survival. This is because the stresses damage the plants' transpiration system, which ultimately affects their capacity to take up water and nutrients. Under stressful circumstances, such as exposure to air pollution when transpiration rates are typically high, a plant's high water content aids in maintaining its physiological equilibrium. It was also reported that a high RWC in plants indicates a high drought resilience capacity [29,30].

For the pH, a significant difference was not found among the rose cultivars ($F = 0.299$, $P = 0.995$) (Fig. 5). The variations in the pH values of the cultivars were closely related; the pH values ranged from 5.57 to 6.33. One study [31] demonstrated that environmental stressors – including inorganic salts, atmospheric NH_3 , and CO_2 – had a direct impact on the pH of plants. As a result, alkaline

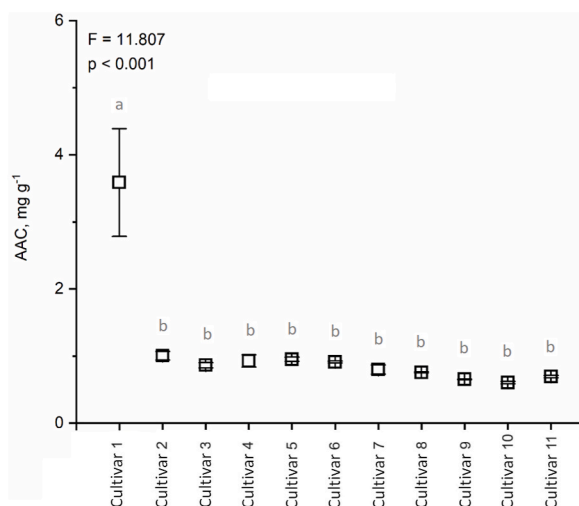


Fig. 2. AAC (mean \pm SD) in the leaves of the studied rose cultivars. Means marked with a common letter are not significantly different.

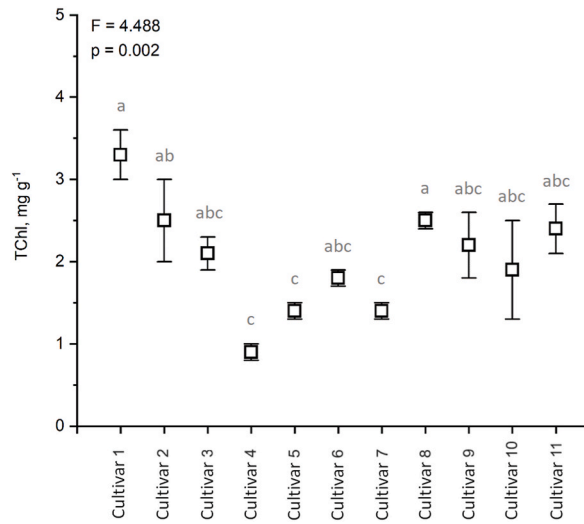


Fig. 3. TChl (mean ± SD) in the leaves of the studied rose cultivars. Means marked with a common letter are not significantly different.

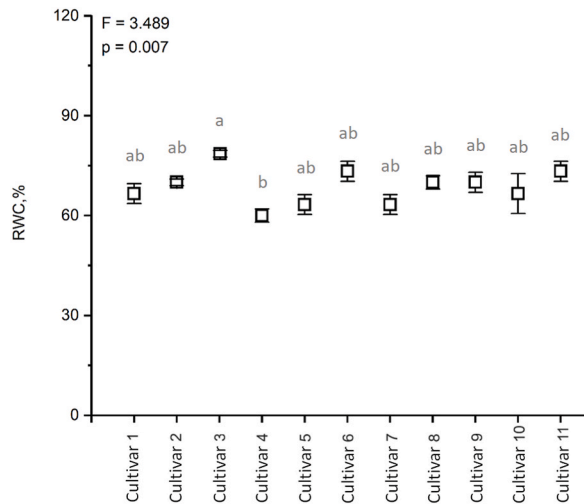


Fig. 4. RWC (mean ± SD) in the leaves of the studied rose cultivars. Means marked with a common letter are not significantly different.

pollutants tend to raise the pH of leaves, whereas acidic pollutants tend to lower it [3]. It was reported that lower pH levels may cause plants to be more sensitive to air pollution, whereas higher pH levels may make plants more tolerant of air pollution [32]. They further explained that if the high pH value is greater than the rate at which hexose is converted to ascorbic acid, a detoxifying mechanism will be established in response, which will increase the tolerance. Low pH levels had a strong association with increased sensitivity to air pollution and lower rates of photosynthesis [33]. Plants with a pH level of around 7 are tolerant to air pollution [29]. Based on the pH level range of the rose cultivars selected for this research, all the samples had pH values that were slightly acidic, showing their individual sensitivity to air pollution. Plant samples with pH values on the acidic side may indicate the likelihood of sulphide and nitrogen oxides in the atmosphere [30]. A similar study [34] had the samples' pH ranging between 5.93 and 6.61, showing slight acidity. The cultivars in this study can be said to be intermediately sensitive based on their closeness in pH ranges.

3.2. Air quality assessment

Seasonal differences were found in the AQI (Fig. 6). A significantly higher value was found in autumn ($F = 8.731, p = 0.007$). Significant differences were also found among seasons based on the main air pollutants: PM ($F = 3.956, p = 0.009$), NO_x ($F = 22.513, p < 0.001$), and SO_2 ($F = 5.031, p = 0.002$) (Table 2). In all seasons, the air was clean based on the AQI, except in autumn, when light air pollution was found.

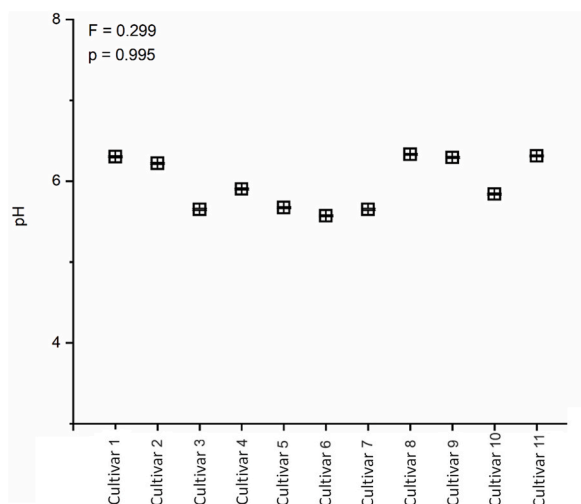


Fig. 5. pH (mean ± SD) in the leaves of the studied rose cultivars.

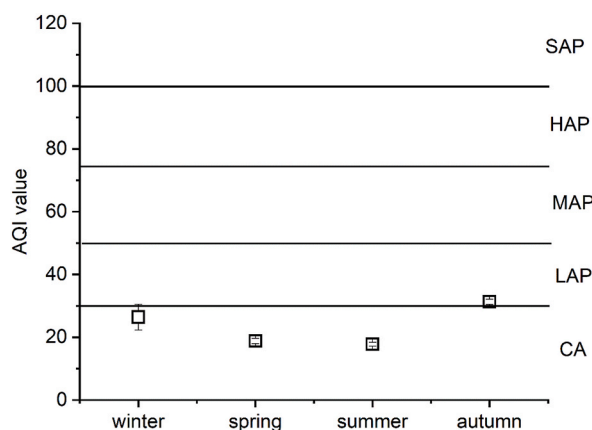


Fig. 6. Seasonality of the AQI in Budapest in 2022. Notation: CA – clean air, LAP – light air pollution, MAP – moderate air pollution, HAP – heavy air pollution, and SAP – severe air pollution.

3.3. Correlation between studied parameters and air pollutants

From the studied parameters, we found a positive correlation only between pH and TChl and between the concentrations of PM₁₀ and NO_x using the Pearson correlation (Fig. 7). This indicates that at increasingly acidic pH levels, there was a notable decline in chlorophyll content. In the case of air pollutants, both PM₁₀ and NO_x are by-products of combustion processes and are frequently present in the atmosphere simultaneously.

4. Conclusions

Urban plants are permanently exposed to air pollution. This causes pollutants to accumulate and integrate into their systems, affecting their biochemical character and tolerance. The findings of this study show that different rose cultivars have various responses to air pollution. This is based on the measurement of biochemical parameters and APTI values. Plants with higher APTI values tend to be tolerant to air pollution, while low APTI values reflect the high sensitivity to air pollutants. We found that all the studied rose cultivars fall into the sensitive category based on their APTI values. While Cultivar 01 had the highest APTI value (10.5), it is still prone to air pollutants just like the rest of the rose cultivars, whose APTI values ranged between 6.8 and 8.5.

Because of increasing vehicle emissions, urbanisation, and the rapid growth of industry, air pollution in metropolitan areas is increasing significantly. Urban areas need to be greened for aesthetic reasons, but plants can also be extremely beneficial for air purification by absorbing air pollutants. Due to their sensitivity to pollution, these rose cultivars can be an ideal choice to plant in polluted areas for urban greening along with tolerant species, to serve as bioindicators in biomonitoring studies.

Table 2
Seasonal variability of air pollutants in 2022 in Budapest (mean \pm SE, $\mu\text{g}/\text{m}^3$).

Air pollutants	Seasons				Threshold limit of EU
	winter	spring	summer	autumn	
PM ₁₀	21.7 \pm 1.1	21.1 \pm 1.0	17.8 \pm 0.7	21.6 \pm 0.9	50
NO _x	43.5 \pm 2.6	41.0 \pm 2.3	22.5 \pm 0.8	47.6 \pm 3.1	150
SO ₂	7.4 \pm 1.3	5.1 \pm 0.2	3.8 \pm 0.1	5.2 \pm 0.2	125

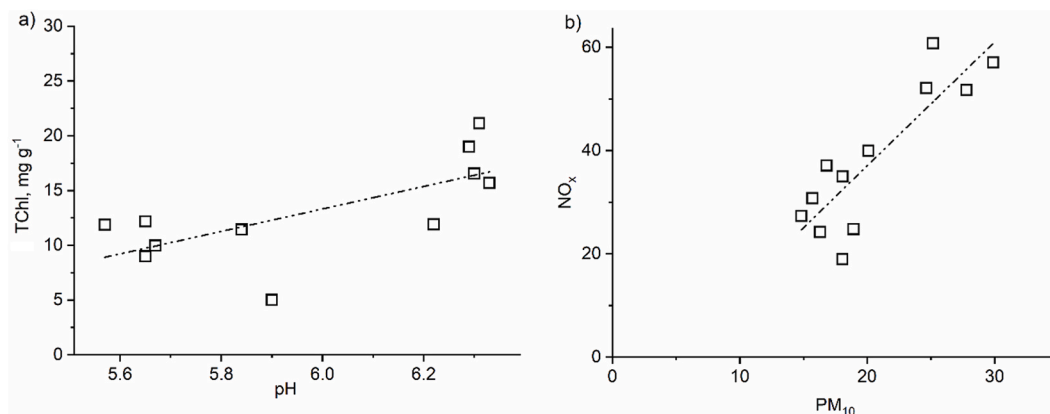


Fig. 7. Relationships between the studied parameters and air pollutants. Notation: TChl – total chlorophyll, pH – pH of the plant leaf extract, NO_x – nitric oxide and nitrogen dioxide, and PM₁₀ – particulate matter ≤ 10 μm in diameter.

CRediT authorship contribution statement

Wanjala Sylvia Nafila: Writing – original draft, Software, Methodology. **László Orlóci:** Writing – review & editing. **Szilvia Kisvarga:** Writing – review & editing. **Gábor Boronkay:** Writing – review & editing. **Béla Tóthmérész:** Writing – review & editing. **Stewart Ajele:** Writing – review & editing. **Vanda Éva Abriha-Molnár:** Writing – review & editing, Software, Methodology. **Edina Simon:** Writing – review & editing, Supervision, Software, Methodology.

Data availability

Data will be made available on request.

Funding sources

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

- [1] WHO, Global Health Risks: Mortality and Burden of Disease Attributable to Selected Major Risks, World Health Organization, Geneva, 2009.
- [2] M. Kuddus, R. Kumari, P.W. Ramteke, Studies on air pollution tolerance of selected plants in Allahabad city, India, *J. Environ. Res. Manag.* 2 (3) (2011) 42–46. ISSN 2141-7466.
- [3] S.K. Singh, D.N. Rao, M. Agrawal, J. Pandey, D. Narayan, Air pollution tolerance index of plants, *J. Environ. Manag.* 32 (1) (1991) 45–55, [https://doi.org/10.1016/S0301-4797\(05\)80080-5](https://doi.org/10.1016/S0301-4797(05)80080-5).
- [4] A. Chauhan, M. Pawar, R. Kumar, P.C. Joshi, Ambient air quality status in uttarakhnad (India): a case study of haridwar and dehradun using air quality index, *J. Am. Sci.* 6 (9) (2010) 565–570.
- [5] M. Das, M. Das, A. Mukherjee, Air Pollution Tolerance Index (APTI) used for assessing air quality to alleviate climate change: a Review, *Res. J. Pharm. Biol. Chem. Sci.* 9 (1) (2018) 45–54.
- [6] P.K. Rai, L.L.S. Panda, Dust capturing potential and Air Pollution Tolerance Index (APTI) of some road side tree vegetation in Aizawl, Mizoram, India: an Indo-Burma hot spot region, *Air Qual. Atmos. Health* 7 (2014) 93–101, <https://doi.org/10.1007/s11869-013-0217-8>.
- [7] P.C. Joshi, A. Swami, Physiological responses of some tree species under roadside automobile pollution stress around city of Haridwar, India, *Environmentalist* 27 (2007) 365–374, <https://doi.org/10.1007/s10669-007-9049-0>.

- [8] M.Z. Iqbal, M. Shafiq, S. Qamar Zaidi, M. Athar, Effect of automobile pollution on chlorophyll content of roadside urban trees, *Global J. Environ. Sci. Manage.* 1 (4) (2015) 283–296, <https://doi.org/10.7508/gjesm.2015.04.003>.
- [9] S. Giri, D. Shrivastava, K. Deshmukh, P. Dubey, Effect of air pollution on chlorophyll content of leaves, *Curr. Agricult. Res. J.* 1 (2) (2013) 93–98, <https://doi.org/10.12944/carj.1.2.04>.
- [10] H. Pfanz, U. Heber, Buffer Capacities of leaves, leaf cells, and leaf cell organelles in relation to fluxes of potentially acidic gases, *Plant Physiol* 81 (2) (1986) 597–602, <https://doi.org/10.1104/pp.81.2.597>.
- [11] J.W. Swanepoel, G.H.J. Krüger, P.D.R. van Heerden, Effects of sulphur dioxide on photosynthesis in the succulent *Augea capensis* Thunb, *J. Arid Environ.* 70 (2) (2007) 208–221, <https://doi.org/10.1016/j.jaridenv.2006.12.014>.
- [12] A.P. Sharma, B.D. Tripathi, Biochemical responses in tree foliage exposed to coal-fired power plant emission in seasonally dry tropical environment, *Environ. Monit. Assess.* 158 (2008) 197–212, <https://doi.org/10.1007/s10661-008-0573-2>.
- [13] S.K. Leghari, M.A. Zaidi, M. Ahmed, K. Nazim, Air pollution tolerance index (APTI) of various plant species growing in quetta city, Pakistan, *J. Biol.* 1 (1) (2011) 81–86.
- [14] S.J. Jyothi, D.S. Jaya, Evaluation of air pollution tolerance index of selected plant species along roadsides in Thiruvananthapuram, Kerala, *J. Environ. Biol.* 31 (3) (2010) 379–386.
- [15] P.L. Conklin, Recent advances in the role and biosynthesis of ascorbic acid in plants, *Plant Cell Environ.* 24 (4) (2001) 383–394, <https://doi.org/10.1046/j.1365-3040.2001.00686.x>.
- [16] S. Ercisli, Chemical composition of fruits in some rose (*Rosa* spp.) species, *Food Chem.* 104 (4) (2007) 1379–1384, <https://doi.org/10.1016/j.foodchem.2007.01.053>.
- [17] V.É. Molnár, E. Simon, B. Tóthmérész, S. Ninsawat, S. Szabó, Air pollution induced vegetation stress – the Air Pollution Tolerance Index as a quick tool for city health evaluation, *Ecol. Ind.* 113 (2020) 1–8, <https://doi.org/10.1016/j.ecolind.2020.10623>.
- [18] E. Simon, V.É. Molnár, D. Lajtos, D. Bibi, B. Tóthmérész, S. Szabó, Usefulness of tree species as urban health indicators, *Plants* 10 (12) (2021) 2797, <https://doi.org/10.3390/plants10122797>.
- [19] M.N. Rao, H.N.V. Rao, *Air Pollution*, Tata McGraw Hill Publishing Company Limited, New Delhi, 1998.
- [20] Hungarian meteorological Service. <https://legszenyezetseg.met.hu/en>, 2023. (Accessed 1 October 2024).
- [21] EU air quality standards. https://environment.ec.europa.eu/topics/air/air-quality/eu-air-quality-standards_en, 2023. (Accessed 1 October 2024).
- [22] C. Priyanka, B. Dibyendu, Biomonitoring of air quality in the industrial town of Asansol using the Air Pollution Tolerance Index approach, *Res. J. Chem. Environ. Environ.* 13 (1) (2009) 46–51.
- [23] U.D. Randhi, M.A. Reddy, Evaluation of tolerant plant species in urban environment: a case study from Hyderabad, India, *Univ. J. Environ. Res. Techn.* 2 (4) (2012) 300–304.
- [24] S.K. Bharti, A. Trivedi, N. Kumar, Air pollution tolerance index of plants growing near an industrial site, *Urban Clim.* 24 (2018) 820–829, <https://doi.org/10.1016/j.uclim.2017.10.007>.
- [25] M.A. Hossain, S. Munné-Bosch, D.J. Burritt, P. Diaz-Vivancos, M. Fujita, A. Lorence, *Ascorbic Acid in Plant Growth, Development and Stress Tolerance*, Springer International Publishing AG, Switzerland, 2018, <https://doi.org/10.1007/978-3-319-74057-7>. ISBN: 978-3-319-74057-7.
- [26] M.W. Davey, M. Van Montagu, D. Inzé, M. Sanmartin, A. Kanellis, N. Smirnof, I.F.F. Benzie, J.J. Strain, D. Favell, J. Fletcher, Plant L-ascorbic acid: chemistry, function, metabolism, bioavailability and effects of processing, *J. Sci. Food Agricult.* 80 (7) (2000) 825–860, [https://doi.org/10.1002/\(SICI\)1097-0010\(20000515\)80:7<825::AID-JSFA598>3.0.CO;2-6](https://doi.org/10.1002/(SICI)1097-0010(20000515)80:7<825::AID-JSFA598>3.0.CO;2-6).
- [27] K. Veni, Marimuthu, K. Lavanya, Air pollution tolerance index of plants a comparative study, *Int. J. Pharm. Pharm. Sci.* 6 (5) (2014) 320–324, <https://doi.org/10.22159/ijpps.2017v9i7.18447>.
- [28] J. Pandit, A.K. Sharma, A Review of effects of air pollution on physical and biochemical characteristics of plants, *Int. J. Chem. Stud.* 8 (3) (2020) 1684–1688, <https://doi.org/10.22271/chemi.2020.v8.i3w.9442>.
- [29] R.N. Lohe, B. Tyagi, V. Singh, P. Kumar Tyagi, D.R. Khanna, R. Bhutiani, A comparative study for air pollution tolerance index of some terrestrial plant species, *Global J. Environ. Sci. Manag.* 1 (4) (2015) 315–324, <https://doi.org/10.7508/gjesm.2015.04.006>.
- [30] A. Nayak, S. Madan, G. Matta, Evaluation of air pollution tolerance index (APTI) and anticipated performance index (API) of some plant species in haridwar city, *Int. J. Environ. Rehab. Cons.* 9 (1) (2018) 1–7, <https://doi.org/10.31786/09756272.18.9.1.101>.
- [31] H.H. Felle, S. Hanstein, The apoplastic pH of the substomatal cavity of *Vicia faba* leaves and its regulation responding to different stress factors, *J. Exp. Bot.* 53 (366) (2002) 73–82.
- [32] A. Roy, T. Bhattacharya, M. Kumari, Air pollution tolerance, metal accumulation and dust capturing capacity of common tropical trees in commercial and industrial sites, *Sci. Total Environ.* 722 (2020) 137622, <https://doi.org/10.1016/j.scitotenv.2020.137622>.
- [33] F.J. Escobedo, J.E. Wagner, D.J. Nowak, C.L. De la Maza, M. Rodriguez, D.E. Crane, Analyzing the cost effectiveness of Santiago, Chile's policy of using urban forests to improve air quality, *J. Environ. Manag.* 86 (1) (2008) 148–157, <https://doi.org/10.1016/j.jenvman.2006.11.029>.
- [34] G. Mahecha, B.R. Bamniya, N. Nair, D. Saini, Air pollution tolerance index of certain plants around SIPCOT industrial area, udaipur (raj.), India, *Int. J. Innov. Res. Sci. Eng. Techn.* 2 (2013) 7927–7929.