GAS EXCHANGE AND LEAF CHLOROPHYLL ESTIMATES OF SOME DECIDUOUS TREE SPECIES DURING AUTUMN SENESCENCE

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Abstract

The ontogenetic cycle of the plant involves going through the phases of seeds, seedlings, juvenile, maturity, and senescence. Leaves senescence of woody plants represents a physiological phase of transition from the nutrient's assimilation to their remobilization to different plant' organs, to ensure the survival of the species and its growth in the following year. The purpose of the present study was to quantify the leaves gas exchanges (photosynthesis rate, transpiration rate, stomatal conductance, and intercellular carbon dioxide content) and to estimate their chlorophyll content, during the autumn senescence, in some deciduous tree species (belonging to 16 different families), grown in the Botanical Garden of the University of Agronomic Sciences and Veterinary Medicine of Bucharest. The obtained data can be added to those already existing, to better understand the plants behaviour during leaves senescence.

Key words: botanical garden, physiology, deciduous trees, leaf senescence.

INTRODUCTION

The ontogenetic cycle of the plant involves going through the phases of seeds, seedlings, juvenile, maturity, and senescence. For individual trees development there are distinguish the following ontogenetic stages: seed, seedling, juvenile, immature (two subgroups), virginal (two sub-groups), young generative, mature generative, old generative and senile (Gatzuk et al., 1980, cited by Evstigneev and Korotkov, 2016).In addition to the ontogenetic cycle of the whole plant, the growth development and trait characteristics of leaves, as the main organs involved in the realization of photosynthesis and respectively the provision of primary products in the ecosystem, directly impact the good functioning of plants within an ecosystem and their behaviour in relation to changes in environmental factors.

If we generally refer to the leaf's senescence, but especially in the case of woody species (ornamental in the urban environment or those in forests), this physiological phase of transition from the assimilation of nutrients to their remobilization (Guo et al., 2021) must be seen mainly as a mean of recycling substances and energy to different plant organs (Li et al., 2020). It is an essential process for plants'

fitness (Guo et al., 2021), which ensures the survival of the species and permits new ensuring growths in the following year. Extending the period of maintaining the leaf green colour can be associated with ensuring the continuity of the carbon dioxide assimilation process from the atmosphere and consequently with a translocation of the photo assimilates to the storage organs. At the same time, there is also the possibility of not achieving an efficient resorption of the substances from the leaves before their abscission. Ensuring carbon and nutrient reserves is all the more necessary for species with deciduous leaves, as opposed to those with persistent leaves, because the former must overwinter and start a new growing season without leaves (Piper, 2020).

Considering the transition from the assimilation of nutrients to their remobilization, the recycling of nitrogen compounds resulting especially as a result of the damage of photosynthetic proteins (to amino acids, amides, ammonium) during the disintegration of chloroplasts (organelles containing over 70% of the total protein content of the mesophyll cells) (Fu et al., 2022) provides an important source of nitrogen that plants will assure as a nutrition supplement for growing organs (e.g., new leaves) and seeds (Masclaux-Daubresse et

al., 2010). In this sense, the studies of Rolny et al. (2011) suggest that the massive leakage of electrolytes that is registered in the case of senescent leaves can be rather associated with the degradation of proteins and the accumulation of ammonium, than with the damage of the membranes as noted by different authors. On the other hand, Tanabe et al. (2022) determined for molecular nitrogen-fixing plants, that nitrogen resorption from senescent leaves was lower than non-fixing ones due to a higher protein content in the leaves of the former. From an aesthetic point of view, the coloring in different shades of the leaves of ornamental trees (urban environment) or from forests (depending on the species) in autumn, during the senescence period, contributes to spectacular autumn scenery (Lee et al., 2003; Li et al., 2020).

The changes regarding the phenology of the leaves, the dynamics of senescence and their fall are of interest not only from a fundamental, physiological point of view, but also for ecological studies, analysis of the carbon cycle in nature (including those regarding the impact of global climate changes on tree species) and prediction of future carbon uptake (Maschler et al., 2022), or why not, from a tourist point of view. In this context, G´omez et al. (2021) analyzed the dynamics of senescence in Spanish beech forests using time series satellite data between 2001 and 2017, as a cost-effective way of working, which can be used by local and regional authorities.

One of the ways of conserving plants and ensuring genetic resources is ex situ conservation, as is the case with botanical gardens, with the focus of studies on morphological characteristics, reproductive technology and conservation value (Sun et al., 2022). They represent a way of protecting living plants, but at the same time they have important roles in environmental beautification, cultural leisure, and climate regulation. For example, even if the natural habitat of the tulip tree species (*Liriodendron tulipifera* L.) is the mountain forests of North America, its leaves have a special ecological plasticity, it can be successfully cultivated in botanical gardens and parks anywhere in the world, thanks to the mechanisms adaptability of the plant (from the point of view of biochemical, physiological, structural, morphological processes) to fluctuations in environmental conditions (Akinshina et al., 2020).

Therefore, the purpose of the present work was the analysis of gas exchanges and to estimate their chlorophyll content during leaf autumn senescence of different deciduous woody species within the USAMV of Bucharest Botanical Garden, under the conditions of the year 2022. The results obtained can be added to those already existing in the specialized literature (Sun et al., 2022), to better understand the mechanisms of adaptation of plants to the environment in the case of a botanical garden and then to establish artificial management conditions on a scientific basis.

MATERIALS AND METHODS

The experimental site and woody species studied.

The study was carried out in the fall of 2022 on 22 deciduous woody species, belonging to 16 different botanical families (Table 1), grown in the Botanical Garden of the Faculty of Horticulture, University of Agronomic Sciences and Veterinary Medicine of Bucharest (USAMV of Bucharest), Romania, North latitude of $44^0 24'$ N and $26^0 05'$ East longitude, and an altitude which varies between 60 m and 90 m above sea level, with a temperate-continental climate.

In situ leaf gas exchange

The measurements on the net CO_2 assimilation (Pn) (μmol CO_2 m^{-2} s^{-1}), transpiration rate (Tr) (mmol H_2O m^{-2}s^{-1}), stomatal conductance (g$_s$) (mol H_2O m^{-2} s^{-1}) and intercellular carbon dioxide concentration (Ci) (μmol CO_2 mol^{-1}) were carried out *in situ* (in a sunny day, between 10:00 and 15:00), using 6 cm^2 chamber of the portable photosynthesis system (LCPro-SD - ADC BioScientific Ltd, Hoddesdon, UK) for still green leaves (GL) and yellow senescent leaves (YL)(with green-yellowish or reddish-green shades depending on the species) (at the moment when the leaf detaches from the plant by simple touch) located on the branches at a height of about 2 m from the ground and with southern exposure.

Table 1. Information on the studied species

Plant family names	No.	Scientific name	Common name
Aceraceae (Sapindaceae)	1.	*Acer platanoides* L.	Norway maple
	2.	*Acer pseudoplatanus* L.	sycamore maple
Anacardiaceae	3.	*Cotinus coggygria* Scop.	"smoke tree"
	4.	*Pistacia vera* L.	pistachio
Betulaceae	5.	*Betula pendula* Roth. (*B. verrucosa*)	European white birch
	6.	*Corylus avellana* L.	the common hazel
	7.	*Corylus colurna* L.	the Turkish hazel
	8.	*Carpinus betulus* L.	the common hornbeam
Caesalpiniaceae	9.	*Cercis siliquastrum* L.	Judas-tree
Calycanthaceae	10.	*Calycanthus floridus* L.	Carolina all spice
Cornaceae	11.	*Cornus mas* L.	cornel
	12.	*Cornus sanguinea* L.	red dogwood
Ebenaceae	13.	*Diospyros virginiana* L.	persimmon
Fagaceae	14.	*Quercus rubra* L. (*Q. borealis* Michx.)	red oak or northern red oak
Ginkgoaceae	15.	*Ginkgo biloba* L.	ginkgo or gingko
Lamiaceae	16.	*Vitex agnus-castus* L.	chaste tree
Magnoliaceae	17.	*Liriodendron tulipifera* L.	yellow-poplar, tulip poplar
Moraceae	18.	*Maclura pomifera* (Rafin.) C.K. Schneid.	Osage orange
Oleaceae	19.	*Forsythia x intermedia* Zabel	golden bells
Scrophulariaceae	20.	*Paulownia tomentosa* (Thunb.) Steud.	paulownia
Tiliaceae	21.	*Tilia tomentosa* Moench (*T. argentea* DC.)	silver lime
Ulamceae	22.	*Celtis occidentalis* L.	common hackberry

Leaf chlorophyll content estimation

Relative leaf chlorophyll content (mg dm^{-2}) was estimated using a portable chlorophyll meter (CCM-300, Opti Science, Hudson, USA) that calculates the total chlorophyll content expressed in mg m^{-2}, based on the fluorescence ratio technique.

Statistical analysis

All parameters measured were expressed as means +/- standard errors (SE). Differences between the leaves collected data (Pn, Tr, g$_s$ and Ci between green and yellowing leaves) were supposed to one way analysis of variance (ANOVA), to detect differences of the same species, as well as to do the comparison between the analyzed species. When the data satisfied the requirements of ANOVA, in Excel T-Test has been used to find which samples where significantly different from statistical viewpoint ($p \leq 0.05$).

RESULTS AND DISCUSSIONS

Leaf level gas exchange during autumnal senescence for 22 deciduous woody species is shown in Table 2. As it can be seen, the average value for net photosynthesis (Pn) was around 0.08 µmol CO_2 m^2 s^{-1}, with maximum Pn recorded in paulownia (GL: 8.788 µmol CO_2 m^2 s^{-1} and 5.146 µmol CO_2 m^2 s^{-1}, respectively for YL). At the opposite pole (with the lowest value of Pn) was found *Q. rubra*, GL (-8.76 µmol CO_2 m^2 s^{-1}). For the most studied species, there were no registered significant differences from statistical point of view, between the rate of photosynthesis in GL, compared to yellow ones.

We found a very highly significant differences ($p < 0.001$) in the case of *G. biloba* and *C. coggygria* (higher values for GL) and, respectively, lower values for them in (*Q. rubra* and *C. betulus*) compared to YLs.

Leaf level transpiration rates (Tr) were highly variable ranging between 0.042 mmol H_2O m^{-2} s^{-1} (*C. floridus* - YL) to 5.24 mmol H_2O m^{-2}s^{-1} (*Q. rubra* - GL) and with a general mean value of 0.83 mmol H_2O m^{-2}s^{-1}. Comparing done in the case of the species (GL vs YL) emphasized non-significant statistical differences for *L. tulipifera, C. betulus, T. tomentosa* and *P. tomentosa,* respectively *($p \geq 0.05$),* while for the majority of species there have been calculated significantly differences ($p \leq 0.001$) (Table 2).

Stomatal conductance (g$_s$) mean values were generally very low (even zero mol H_2O m^{-2} s^{-1}) (GL and/or YL). The higher value was only of 0.145 mol H_2O m^{-2} s^{-1} (*Q. rubra* - GL) (Table 2).

Table 2. Gas exchange parameters: (Pn) (net photosynthesis - $\mu mol\ CO_2\ m^{-2}\ s^{-1}$); (Tr) (transpiration rate - $mmol\ H_2O\ m^{-2}s^{-1}$; (g_s) (stomatal conductance – $mol\ H_2O\ m^{-2}\ s^{-1}$) and intercellular carbon dioxide concentration (Ci) ($\mu mol\ CO_2\ mol^{-1}$) in leaves of 22 deciduous woody species, in autumn

Species	Characteristic of the leaf								the p value and the significance of the differences			
	Green Leaf (GL)				Yellowed Leaf (YL)							
	Pn	Tr	g_s	Ci	Pn	Tr	g_s	Ci	Pn	Tr	g_s	Ci
A. platanoides	0.04 ± 0.06	0.99 ± 0.07	0.02 ± 0.002	419.4± 9.66	-0.36 ± 0.21	0.35 ± 0.04	0	507± 12.14	0.09 ns	<0.001 xxx	-	0.02 0
A. pseudoplatanus	0.17 ± 0.38	0.83 ± 0.005	0.02 ± 0	419 ± 23.81	-0.39 ± 0.29	0.22 ± 0.007	0	478.2 ± 63.91	0.46 ns	1.74989E-07 xxx	-	0.51 ns
C. coggygria	0.17 ± 0.13	1.75 ± 0.14	0.04 ± 0.003	397.6 ± 4.24	-0.91 ± 0.11	0.61 ± 0.008	0.01 ± 0	504.8 ± 12.35	0.0009 xxx	<0.001 xxx	<0.001 xxx	<0.001 000
P. vera	-0.33 ± 0.10	1.29 ± 0.15	0.026 ± 0.004	441.2 ± 11.85	0.23 ± 0.15	0.84 ± 0.07	0.016 ± 0.002	390.6 ± 9.81	0.01 00	0.0097 xx	0.03 x	0.01 xx
B. pendula	0.89 ± 0.22	2.11 ± 0.10	0.09 ± 0.005	393.2 ± 9.75	0.39 ± 0.05	0.29 ± 0.07	0.01 ± 0	434.6 ± 32.20	0.12 ns	<0.001 xxx	<0.001 xxx	0.27 ns
C. avellana	0.52 ± 0.44	0.22 ± 0.04	0	369.6 ± 14.05	0.30 ± 0.16	0.41 ± 0.02	0	357.8 ± 26.55	0.58 ns	<0.001 000	--	0.66 ns
C. colurna	-0.61 ± 0.07	0.37 ± 0.01	0	530.4 ± 19.19	0.16 ± 0.25	0.26 ± 0.01	0	467.4 ± 15.54	0.02 0	0.0004 xxx	-	0.07 ns
C. betulus	-2.71 ± 0.19	0.79 ± 0.12	0.012 ± 0.0002	654.2 ± 32.32	-0.35 ± 0.06	0.77 ± 0.05	0.01 ± 0	438 ± 5.6	<0.001 000	0.85 ns	0.37 ns	0.003 xx
C. siliquastrum	2.01 ± 1.07	1.36 ± 0.16	0.04 ± 0.004	375.6 ± 29.69	-0.11 ± 0.16	0.33 ± 0.02	0	415.4 ± 28.69	0.17 ns	0.003 xx	-	0.36 ns
C. floridus	2.19 ± 0.82	1.89 ± 0.08	0.04 ± 0.003	357.2 ± 32.73	-0.46 ± 0.55	0.04 ± 0.003	0.01 ± 0.0002	438.8 ± 47.70	0.06 ns	<0.001 xxx	<0.001 xxx	0.69 ns
C. mas	0.29 ± 0.11	0.17 ± 0.02	0	330.6 ± 10.37	0.39 ± 0.13	0.13 ± 0.02	0	299.6 ± 17.69	0.69 ns	<0.001 xxx	-	0.37 ns
C. sanguinea	0.04 ± 0.05	0.13 ± 0.007	0	386.6 ± 24.64	-0.11 ± 0.10	0.65 ± 0.03	0	429.6 ± 12.26	0.32 ns	<0.0001 000	-	0.14 ns
D. virginiana	0.17 ± 0.39	2.95 ± 0.19	0.07 ± 0.005	409.8 ± 9.61	-0.004 ± 0.17	1.34 ± 0.10	0.02 ± 0.002	417.6 ± 11.66	0.73 ns	<0.001 xxx	<0.001 xxx	0.69 ns
Q. rubra	-8.76 ± 0.21	5.24 ± 0.09	0.15 ± 0.004	527.4 ± 2.27	-0.45 ± 0.28	0.84 ± 0.03	0.01 ± 0.002	454.8 ± 9.83	<0.001 000	7.28069E-06 xxx	5.65E-05 xxx	0.004 xx
G. biloba	0.35 ± 0.06	0.23 ± 0.005	0	280 ± 7.86	-0.60 ± 0.11	0.15 ± 0.006	0	575 ± 71.24	0.001 xxx	<0.001 xxx	-	0.02 0
V. agnus-castus	-0.41 ± 0.39	0.91 ± 0.04	0.02 ± 0	445.6 ± 32.80	-0.50 ± 0.12	0.31 ± 0.01	0	510.4 ± 25.77	0.84 ns	9.91203E-05 xxx	-	0.17 ns
L. tulipifera	2.23 ± 0.71	1.74 ± 0.24	0.04 ± 0.008	362.4 ± 19.80	-2.08 ± 0.32	1.86 ± 0.08	0.04 ± 0.003	480.2 ± 11.53	0.002 xx	0.61 ns	>0.05 ns	0.003 00
M. pomifera	0.48 ± 0.18	0.45 ± 0.02	0	317 ± 32.24	-0.36 ± 0.19	0.32 ± 0.02	0	450.4 ± 50.32	0.03 x	<0.001 xxx	-	0.09 ns
F. x intermedia	0.29 ± 0.13	0.29 ± 0.07	0	367 ± 52.12	-0.81 ± 0.37	0.19 ± 0.01	0	587 ± 81.0	0.08 ns	<0.001 xxx	-	0.12 ns
P. tomentosa	8.79 ± 0.63	0.08 ± 0.007	-	-	5.15 ± 0.11	0.07 ± 0.007	-	-	0.004 xx	0.39 ns	-	-
T. tomentosa	-0.62 ± 0.28	0.51 ± 0.04	0.008 ± 0.001	483.8 ± 28.59	-1.07 ± 0.47	0.45 ± 0.008	0.008 ± 0.001	611.6 ± 37.77	0.59 ns	0.24 ns	-	0.14 ns
C. occidentalis	2.01 ± 1.07	1.36 ± 0.16	0.04 ± 0.004	375.6 ± 29.69	-0.11 ± 0.16	0.33 ± 0.02	0	415.4 ± 28.69	0.17 ns	0.003 xx	-	0.36 ns

The data are shown as mean ± SE (n = 5). The comparison was done by the paired T-Test, in Excel, by comparing the values of green and yellow leaves, within the same species. $p \geq 0.05$: There is no statistically significant differences; $p \leq 0.05$: There is statistically significant difference at 95% confidence level; $p \leq 0.01$: There is statistically significant difference at 99% confidence level, $p \leq 0.001$: There is statistically significant difference at 99.99% confidence level.

Intercellular carbon dioxide concentration (Ci) varied between 280 µmol CO_2 mol^{-1} (*G. biloba* - GL) and 654.2 µmol CO_2 mol^{-1} (*C. betulus* - GL). Data presented in Table 2 show that there were not significantly differences between GL and YL ($p \geq 0.001$) with some exceptions, as for example *C. coggygria*, (GL - the mean value of 397.6 µmol CO_2 mol^{-1} as compared with YL -504.8 µmol CO_2 mol^{-1} ($p \leq 0.001$) (Table 2). Total estimated chlorophyll content mean values are shown in Figure 1. As we can see, there are evident significant differences between GL and YL, as well as between the studied species (Figure 1, Table 3). The maximum value has been registered for GL of *A. pseudoplatanus* (7.13 mg dm^{-2}), followed by *T. tomentosa* (7.09 mg dm^{-2}), while the lowest one was noticed for leaves of *G. biloba* (5.75 mg dm^{-2} - GL; 5.46 mg dm^{-2} - YL, respectively).
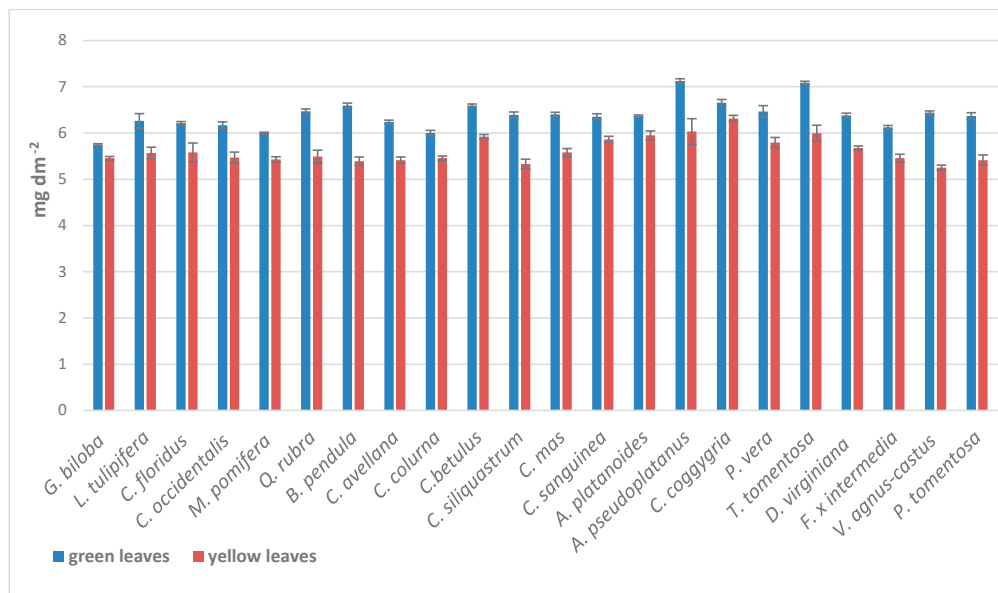

Figure 1. Total chlorophyll content estimated with CCM-300 chlorophyll meter (means ± SE; n=5)

Table 3. The ANOVA: Two-Factor with Replication results showing the effects of species, leaves colour, and their interactions on estimated chlorophyll content

Source of variation	sum of squares (SS)	degrees of freedom (df)	mean square (MS)	F-statistic (F)	*p*-value	critical F-value (F crit)
Sample - Species	14.81397	21	0.705427	16.51289	2.4E-31	1.61629
Columns- Leaf colour	31.44204	1	31.44204	736.0067	8.91E-65	3.894838
Interaction	3.75723	21	0.178916	4.188124	5.41E-08	1.61629
Within	7.51868	176	0.04272			
Total	57.53192	219				

The statistical significance of the differences between total chlorophyll values of the measured tree species was determined by variance analysis (Table 3). Accordingly, between species, as well as between different coloured leaves measurements, there were statistically significant differences between mean values at 99.99 % confidence level (p-value ≤0.001; F-statistic ≥ F critic).

Our study adds to the scientific literature some insights and potential mechanisms in explaining leaf different responses of different species to autumn conditions, in a temperate climate, during plant transition from the active to the dormancy period.
During leaf senescence a nutrient resorption take place with a view to assure a new leaves formation in the next year. Thus, as Yu et al.

(2022) also noticed, duration of the leaf senescence, physiological processes rates in this period and therefore, the efficient mobilization of the nitrogen may affect the growth of leaves in the next season.

Photosynthesis is the most important physiological process specific to autotrophic, green plants. Its intensity depends on the influence of numerous abiotic (e.g., temperature, light, water, carbon dioxide, etc.) and biotic factors. At the same time, the genetic characteristics of the species leave their mark on its dynamics and other associated processes (Zhang et al., 2021). Last, but not least, the photosynthetic capacity is an indicator through which the degree of adaptability of plants to a certain habitat can be characterized.

It is possible that the high rate of the net photosynthesis, even if the stomata are closed, is due to an increased capacity to refix the internal carbon dioxide resulting during respiration (and photorespiration), as well as an increase in the resistance of the mesophyll, which reduces the diffusion process of CO_2 from the cell to the atmosphere. This is how it can be explained that the species that have a higher resistance at the mesophyll level and with thicker cell walls can be more efficient in using the internal carbon dioxide resulting from the respiration process (Eckert et al., 2021).

According to the results obtained by Yu et al. (2022), trees reduce their photosynthesis rate and shorten their growing season to trigger senescence and make the nitrogen remobilization process more efficient. However, if senescence sets in too late, the plants can accumulate a greater amount of photo assimilates, but there is a risk of exposure to damage caused by frost, along with the decrease in the storage of nutrients (e.g., nitrogen loss in leaves) necessary to support the growth of leaves in the following season.

We found very low values of Pn at *Q. rubra* which agree with data obtained by Dhillon (2017) who studied the seasonal dynamics of the process whose rate varied by a maximum of +6,325 µmol CO_2 $m^{-2}s^{-1}$ (in May), at a minimum of -0.618 µmol CO_2 $m^{-2}s^{-1}$ (end of October) during senescence.

For the transpiration rate, the trend was similar, the maximum values being recorded also in May (+1,278 mmol H_2O m^{-2} s^{-1}), and at the end of October a significant decrease of it was reached (+0,191 mmol H_2O m^{-2} s^{-1}).

V. agnus-castus was characterized as the most sensitive and vulnerable in forest-steppe conditions of Ukraine, needs constant replenishment, having high water loss due to transpiration, also the lowest intensity of photosynthesis and dark respiration (Levchyk and Levon, 2018).

In our study, in the case of the *G. biloba* (which is not a native species) a faster and more extensive process of yellowing of the leaves was noted, respectively a faster and massive fall of them, compared to the other studied species, where the fall of the leaves was gradual. In previous studies done in Beijing, China, Zhang et al. (2021) reveals the fact that during senescence (autumn), there is a decrease in the chlorophyll content and an increase in the concentration of carotenoids, as well as changes in the rate of photosynthesis, in close relation with changes in environmental factors, but also depending on the variety and the types of scions. At the same time, the authors recorded in October a decrease in the intercellular CO_2 concentration, in the rate of transpiration, as well as in g_s, compared to July. The colour changes of the leaves during senescence also reflect their nutritional status and, respectively, the degree of nutrients re-translocation. In the case of red-coloured leaves, a more intense translocation process may occur due to the presence of anthocyanins, more resistant to photoinhibition compared to carotenoids, while in green leaves, during senescence, nutrient resorption it was reduced (Zhang et al., 2021).

In the case of some species studied by us, a reddish colouring of the leaves was observed, which may represent a specific characteristic of the species. This may influence the way the physiological processes unfold during senescence, considering including the positive effects that the accumulation of anthocyanins in the leaves can have for the protection of the photosynthetic apparatus in the case of the excess light energy.

Regarding the senescent autumn leaves of the *Cornus stolonifera* species, Field et al. (2001) highlighted the fact that if they are exposed directly to sunlight, they turn reddish-purple, because of the accumulation of anthocyanins in

the vacuoles of the palisade tissue cells and were named "red senescing" On the other hand, the leaves positioned in sub-canopy environments did not contained anthocyanins, were pale yellow green in colour and were named as "yellow senescing"

Lee et al. (2003) highlighted the fact that during leaves senescence, 70% of the woody species contained anthocyanins, synthesized *de novo*, even if they did not appear red, in the situation where the chlorophyll is in an amount less than 20 μg cm^{-2}. Also, the nitrogen content was lower in species with red leaves, which means a better nitrogen resorption in such species.

In addition to the environmental beautification, cultural leisure, and climate regulation, Botanical Gardens are an important sector of the *ex situ* plant conservation (Peschardt and Stigsdotter, 2013, cited by Sun et al., 2022) where very different species can be found, which are grown in an environment completely different from the wild one, and for whose care artificial management is applied.

In similar growing conditions, different plant species expressed in most cases similar values of the eco-physiological characteristics. So, for example, the results of the studies of 47 woody species existing in Botanical Garden in Beijing, highlighted the fact that the apparent quantum efficiency (AQY), light compensation point (LCP), dark respiration (Rd) values were not significantly different between different forms of life, while for the light saturation point (LSP), the net photosynthetic rate at light saturation and specific leaf area (SLA) the differences were significant. Thus, in the artificial environment of the botanical garden acclimated to similar environments, and that the environment had a greater impact on the photosynthetic parameters but had little effect on the SLA and chlorophyll (SPAD values) of plant leaves (Sun et al., 2022).

The increased photosynthetic capacity in different environmental conditions and the rapid growth of *Paulownia* trees was attributed by some authors to their use of C_4 type photosynthesis. But, Young and Lundgren (2022) did a careful analysis of the citations that come to support this idea and the conclusion reached was that there is no scientific data to support this statement.

However, the author mentions the fact that numerous investment schemes use information on the physiology of the species (including photosynthesis) to legitimize its use for financial investments and offsetting carbon emissions. The authors confirmed that for *P. tomentosa*, the saturation light level was 1000 μmol m^{-2} s^{-1}, CO_2 compensation point at 63.81 μmol mol^{-1}, water use efficiency 104.54 mmol mol^{-1} and carboxylation efficiency 0.05 mol m^{-2} s^{-1}, respectively, consistent with C_3 photosynthesis type.

The high values of the net photosynthesis rate in the case of the species *Liriodendron tulipifera*, compared to the other species studied, agree with data presented by Akinshina et al. (2020). The species is characterized as being a light-loving mesophilic species, and as having a relatively increased ecological plasticity to light and temperature, which leads to the favouring of the photosynthesis process if the leaves are exposed to increased light intensity and high temperature (as were the conditions in October 2022). To this is added the anatomical changes at the level of the leaves, which provide protection against overheating, and which contribute to the efficient regulation of the plant's temperature, simultaneously with a better supply of water, but also the preservation of water in the plant.

The rate of the photosynthesis process depends on the characteristics of the chloroplasts, organelles exposed to a continuous process of acclimatization to environmental conditions, to which are added the changes associated with the development of the phases of the normal development cycle. During the senescence period, because of their disorganization, they constitute an important source of intermediate metabolites, which will be remobilized to the storage tissues (Domínguez and Cejudo, 2021). In addition, leaf colour is one of the most important characteristics for plants used for landscape and ornamental purposes (Zhang et al., 2022). Genetic studies by Zhang et al. (2022) highlighted the fact that the silencing of two genes (*ChlH* - magnesium chelatase Subunit H and *POLGAMMA2* – POLYMERASE GAMMA 2) may be related to the phenotype of *Forsythia* with yellow leaves, through the direct or indirect influence of genes

involved in chlorophyll biosynthesis and development chloroplast.

Also, the studies carried out on *G. biloba*, by Li et al. (2020) brought clarification regarding the elucidation of the mechanisms of leaf colour change during senescence. There was a significant decrease in the expression of genes for the biosynthesis of chlorophyll *b*, an increase in the expression of genes involved in the biodegradation of chlorophyll, as well as the expression of other genes relative to senescence (such as those related to abscisic acid, jasmonic acid, autophagy, or transcription factors - WRKY, and NAC), whereas cytoskeleton-, photosynthesis-, and antioxidation-related genes decreased from the green leaf stage to the yellow leaf stage.

In the conditions of global climate change, due to the positive effect of higher temperatures, an increase in the duration of the growing season is expected, together with the deposition of nutrients and the assimilation of carbon dioxide, while a limitation of the sink could represent a driver of autumn leaf senescence in deciduous trees (Maschler et al., 2022). Krasnova et al. (2022) studied the effects of the heat wave in the summer of 2018 in Europe on different species (coniferous, deciduous, and conifer-broadleaved) and highlighted the fact that coniferous forests were more resistant to thermal shock, possibly due to the adaptation to a lower water content in the soil. On the other hand, the mixed forest (conifer-broadleaved forest) (pine, spruce, birch, clear-cuts) was more strongly affected compared to the pine forest. From a net CO_2 accumulator in 2017, it became a net CO_2 source in 2018, with a three times higher carbon release, a reduction in gross primary production and a decrease of net ecosystem exchange.

In perspective, implementation of genome editing techniques or control of interest gene expression (e.g., CRISPR/Cas9 system) could also be used to modulate leaf senescence, with the aim of improving agronomic traits, both in terms of crop yields and post-harvest quality (Kim et al., 2018).

CONCLUSIONS

Overall, our results suggest that deciduous species belonging to different botanical families, and with different origins have a specifical physiological behaviour during the autumnal senescence in a botanical garden, in temperate climate conditions. Some native species, as well as those known to have a great adaptation capacity to varied environmental factors seems to be more performed as compared with non-native ones.

The negative photosynthesis rate registered may be due to an intensification of the respiration rate with surpass the former one, and this can signify that the catabolism processes that take place in leaves are those which will also represent the start point for a translocation process before leaves fall, to have a better preparing plant for the winter season, with a view to a successful vegetation start at the next season.

On the other hand, sometimes, a high net photosynthesis values are linked with a higher intercellular carbon dioxide concentration produced by the respiration (adding its reassimilation) and which cannot diffuse into the atmosphere because of the very low values of stomatal conductance or even of their closure, in a drought climate and high temperature conditions such as those specifically under current study area.

Chlorophyll content decreasing is a usual leaf process during senescence. First, it depends on the species characteristic features and chlorophyll breakdown can contribute to the plant redistribution of the nitrogen compounds in perennial plant organs.

Our study riches the knowledge of plants adaptation to the changing environmental conditions and helps to establish the scientific conditions of artificial management.

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