The use of red species for urban "greening" in the age of climate change

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ABSTRACT. – The red/purple colour of some plant species is due to the presence of anthocyanins, a colourful class of flavonoids widely spread in the *Plantae* kingdom. Beside a doubtless aesthetic value of anthocyanin-rich species, the presence of these pigments confers them peculiar physiological and biochemical properties which make red species usually more tolerant to some environmental stresses, as occur in Mediterranean area. The ability of anthocyanins to partially absorb a proportion of light striking the mesophyll (mainly green and yellow wavebands) represents a useful feature against a condition of excessive light which not only occurs when plants are subjected to high irradiances, but also when other stressors (*e.g.*, high temperature, low water availability) impair the photosynthetic process. The work elucidates as the presence of anthocyanins determines morpho-anatomical, biochemical and physiological effects. In particular, the roles of these pigments are described comparing the leaf ontogenesis of two genotypes of *Prunus cerasifera*, one with red (var. *Pissardii*) and one with green leaves (clone 29C). Red-leafed *Prunus* resulted better protected, especially during the leaf senescence. The presence of anthocyanins also promotes a delayed leaf senescence (4-week-longer leaf lifespan) which is a well-appreciated feature in the context of urban "greening".

INTRODUCTION. – Anthocyanins, one of the most conspicuous classes of flavonoids and, together with proanthocyanidins and flavonols, are important plant pigments responsible for the red, pink, purple, and

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blue colours in plants (Grotewold 2006). From the Antarctic purple-coloured leafy liverwort *Cephaloziella exiliflora*, to the breathtaking North American woodland trees (painted by intense autumn-red leaves in species such as *Acer rubrum*), the black foliage of *Ophiopogon planiscapus* "Nigrescens" (native to Japan), the intense purple-leafed *Prunus cerasifera* (widely dispersed in the Mediterranean basin and Southwest Asia), and the red-pigmented leaf margin of *Pseudowintera colorata* (from New Zealand), anthocyanic foliage is widespread throughout the plant kingdom and occurs all around the world.

Because anthocyanins also occur so commonly across disparate vegetative organs, there has been concerted research effort to understand their functional significance, particularly in plants that experience abiotic stressors (Chalker-Scott 1999; Landi *et al.* 2015). Among others (*e.g.*, herbivory deterrence, camouflage, antioxidants, metal chelators), the most accepted hypothesis for foliar anthocyanins is that these pigments act as sunscreen, thereby protecting the leaves from adverse situation of excessive light (respect to the capacity of the leaf to use it), namely *photoprotection*.

When the incident radiant flux exceeds the plant's ability to utilize or dissipate that energy, the excess excitation energy within the photosynthetic apparatus can lead to impairment of chloroplast performance and a reduction in carbon fixation. Plants have developed various mechanisms (both morphological and physiological) to avoid or accommodate excessive irradiance, such as leaf or chloroplast movement, reactive oxygen species (ROS) scavenging systems, dissipation of absorbed light energy as heat, activation of cyclic electron flow and photorespiratory pathways (Takahashi & Badger 2011). The biosynthesis of UV- and visible light-absorbing compounds (*e.g.*, phenylpropanoids) may further contribute to attenuate the burden of excessive irradiance (Agati & Tattini 2010). There is substantial empirical evidence that foliar anthocyanins can protect chloroplasts from the adverse effects of excess light (Landi *et al.* 2015). Anthocyanins have the potential to reduce both the incidence and the severity of photo-oxidative damage by intercepting a portion of supernumerary photons that would otherwise strike the chloroplasts, thus increasing ROS production and ROS-triggered damage (Fig. 1). For these reasons, in most cases red genotypes result better protected than greens under a plethora of environmental stressors which impair the photosynthetic process (Landi *et al.* 2015).

RED AND GREEN LEAFED *PRUNUS*. – As young and senescent leaves are usually more vulnerable to conditions of damage from excessive light, namely photoinhibition (Juvani *et al.* 2013), epidermally-located anthocyanins, photoprotecting the subjacent mesophyll cells may improve the photosynthetic performance of red morphs, making them more competitive in limiting conditions or in condition in which the leaves are more vulnerable (*i.e.*, young and senescent leaves). To test this hypothesis, Lo Piccolo *et al.* (2018) conducted a study in which morpho-metric and photosynthetic parameters as well as pigment content were determined in two morphs of *Prunus cerasifera* with permanent red (var. *Pissardii*; RLP) or green (clone 29C; GLP) leaves from their juvenility (1-week-old leaves) to their (early) senescence (13-week-old leaves).

A low photosynthetic rate in mature leaves of red genotypes was already reported in *Prunus* spp. (Kyparissis *et al.* 2007) and also confirmed by Lo Piccolo *et al.* (2018). Indeed, mature leaves of RLP had a ~30% lower photosynthetic rate compared to GLP. This lower CO_2 photoassimilation in RLP was attributable to the lower irradiance reaching chloroplast due to the anthocyanin presence. The sunscreen effect may appear as a negative feature for the plant, which however becomes very important when the leaves are in excessive light conditions, as in the juvenile and mature phase. Consequently, Lo Piccolo *et al.* (2018) observed that the decline of photosynthetic rate was less pronounced in senescent leaves of red than green *Prunus*, which also showed lower level of oxidative stress (measured in terms of hydrogen peroxide accumulation and super oxide anion production). As a consequence, an increased leaf lifespan of red leaves (4-week-longer than green leaves) and an increased level of recycled nitrogen were detected in RLP (Lo Piccolo *et al.* 2018). The capacity of anthocyanins to retard the leaf senescence, thereby extending the leaf lifespan suggests a "conservative-use strategy" adopted by species with "long-lived organs" (*e.g.*, evergreens) which inhabit nutrient-limiting environments in which a slower turnover of plant organs is advantageous (Valladares *et al.* 2000). On the other hand, green *Prunus* behaves like a fast-growing species that maximizes the biomass yield during favourable conditions and for which the loss of a higher level of N by leaf fall can be easily compensated by enhanced uptake mechanisms from soil in the following growing season.

CONCLUSION. – Several groups at the Department of Agriculture, Food and Environment of the University of Pisa have a long-running interest in the issue of climate change/plant interactions. Thanks to these experimental activities, physiological, biochemical and molecular responses to climate change-related abiotic stressors of several crop and tree species have been largely elucidated in the last decades. The abovementioned results highlight that the presence of anthocyanins in red *Prunus* represents a useful feature in condition of imbalance of absorbed/utilized light irradiance and also pointed out the possibility to use red-leafed *Prunus* in urban environment due to its capacity to maintain their canopy for longer (about one month longer in autumn) than green *Prunus* genotypes (Fig. 2). This experimental approach represents a good example of physiological research applied to the amelioration of ecosystem services by urban tree, and confirms that the use of red species for urban "greening" is a promising strategy in the age of climate change.

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REFERENCES

Agati G., Tattini M. (2010). Multiple functional roles of flavonoids in photoprotection. New Phytologist 186: 786-793.

Chalker-Scott L. (1999). Environmental significance of anthocyanins in plant stress responses. Photochemistry and Photobiology 70: 1-9.

Grotewold E. (2006). The genetics and biochemistry of floral pigments. Annual Review in Plant Biology 57: 761-780.

Juvany M., Müller M., Munné-Bosch S. (2013). Photo-oxidative stress in emerging and senescing leaves: A mirror image. Journal of Experimental Botany 64: 3087-3098.

Kyparissis A., Grammatikopoulos G., Manetas Y. (2007). Leaf morphological and physiological adjustments to the spectrally selective shade imposed by anthocyanins in *Prunus cerasifera*. Tree Physiology 27: 849-857.

Landi M., Tattini M., Gould K.S. (2015). Multiple functional roles of anthocyanins in plant-environment interactions. Environmental and Experimental Botany 119: 4-17.

Lo Piccolo E., Landi M., Pellegrini E. *et al.* (2018). Multiple consequences induced by epidermally-located anthocyanins in young, mature and senescent leaves of prunus. Frontiers in Plant Science 9: article number 917.

Takahashi S., Badger M.R. (2011) Photoprotection in plants: a new light on photosystem II damage. Trends in Plant Science 16: 53-60.

Valladares F., Martinez-Ferri E., Balaguer L. *et al.* (2000). Low leaf-level response to light and nutrients in Mediterranean evergreen oaks: A conservative resource-use strategy? New Phytologist 148: 79-91.

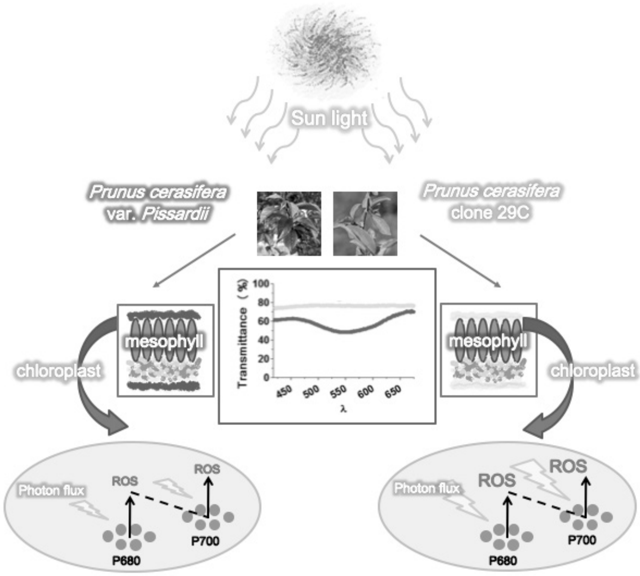

Fig. 1. Sunlight attenuation mechanism proposed for anthocyanins in red pigmented leaves to the green leaves. The abatement by anthocyanins of a proportion of light that would otherwise strike chloroplasts, as illustrated by a lower transmittance through the upper epidermis of red leaves, reduces the amount of reactive oxygen species (ROS) generated from the photosynthetic electron transport chain in photosystem II (PSII) and photosystem I (PSI). Modified from Landi *et al.* (2015).

Fig. 2. Seedlings of *Prunus cerasifera* clone 29C (left) and *P. cerasifera* var. *Pissardii* (right) at the beginning of November 2017, when red leaves were 17-week-old and leaves from clone 29C were completely fallen.