BRIEF COMMUNICATION

Are red leaves photosynthetically active?

F. POMAR* and A. ROS BARCELÓ**[,1]

*Centro de Investigaciones Agrarias de Mabegondo, Apartado 10, E-15080 La Coruña, Spain**
*Department of Plant Biology (Plant Physiology), University of Murcia, E-30100 Murcia, Spain***

Abstract

At irradiances close to those representing a sunny day, red and green leaves of poinsettia (*Euphorbia pulcherrima*) showed only minor differences in their photosynthetic capacities despite the strong differences in their pigment composition. However, contrarily to green leaves, red leaves did not show inhibition of photosynthesis at high irradiances, because anthocyanins protected chloroplasts from photoinhibition.

Additional key words: anthocyanins, chlorophyll fluorescence, *Euphorbia*, photochemical and non-photochemical quenching, photosystem 2, poinsettia.

Apical leaves of many temperate deciduous plants turn brilliant red in autumn (Gould *et al*. 1995). Unlike yellow and orange senescing autumn leaves, where chlorophyll (Chl) breakdown unmasks the already present carotenoid pigments, most red leaves result from the *de novo* synthesis of anthocyanins, although why anthocyanins are synthesized in autumn leaves just before they are shed is unclear (Gould *et al.* 1995). Anthocyanin synthesis in autumn leaves often precedes Chl breakdown and the colour intensity of red leaves is generally increased by high irradiance, cool (but not freezing) temperatures, and mild drought (Gould *et al*. 2000). In natural populations, leaf reddening is usually observed in conjunction with the onset of low temperatures in the autumn in plants growing under moderate to high irradiance but not in shaded populations. In perennial plants, leaves typically re-green in the spring with rising temperatures, indicating that leaf reddening is part of seasonal acclimation to low temperatures and high irradiances rather than a senescence response (Gould *et al.* 2000).

The emission of Chl fluorescence by leaves is intrinsically associated with photosynthesis since it reveals the current status of photochemical processes (Müller *et al.* 2001). At room temperature, Chl fluorescence mainly originates from the photosystem 2 (PS 2). Chl fluorescence quenching, which monitors the extent of photochemical (q_P) and non-photochemical (q_{NP}) processes (Müller *et al.* 2001), is usually measured with a commercial fluorometer that can measure fluorescence yield in the presence of background “white light”. This apparatus allows to answer the easily understood question: Are red leaves photosynthetically active?

Flowering plants of poinsettia (*Euphorbia pulcherrima* Willd.) were purchased in a local market. The coloured leaves in poinsettia are provided by the bracts, leaves whose auxiliary bud differentiates into flowers (Kannangara and Hansson 1998). Modulated Chl fluorescence was measured in dark-adapted green and red leaves with a *PAM-210* pulse chlorophyll fluorometer (*H. Walz*, Effeltrich, Germany). From the experimental fluorescence values, the quantum yield of PS 2 photochemistry (Φ_{PS2}), the linear electron transport rate (ETR), the non-photochemical quenching (q_{NP}), and the photochemical quenching (q_P) were calculated according to Pomar *et al.* (2004). Chl content was determined as described (Cuello 1997).

Red (upper) and green (lower) leaves of poinsettia accumulate a different set of pigments. Extraction of red leaves with acetone containing 0.1 M HCl at 80 ºC revealed the presence of red compounds, which showed a λ_{max} at 529 nm, while the extraction of green leaves with 80 % (v/v) ethanol at 80 ºC revealed the presence of Chls (Fig. 1).

Both red and green poinsettia leaves are able to use photons efficiently to perform photosynthesis in the range of irradiances common on the Earth’s surface

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Abbreviations: Chl - chlorophyll; ETR - electron transport rate; PAR - photosynthetically active radiation; PS 2 - photosystem 2; q_{NP} - nonphotochemical quenching; q_P - photochemical quencing; Φ_{PS2} - quantum yield of PS 2 photochemistry.
[1] Corresponding author: fax: (+34) 968 363 963, e-mail: rosbarce@um.es

[photosynthetically active radiation, PAR ≤ 2 000 μmol(photon) m^{-2} s^{-1}]. As expected, the values of Φ_{PS2} (Fig. 2*A*), ETR (Fig. 2*B*), and q_P (Fig. 2*C*) were lower for red leaves than for green leaves, especially for intermediate PAR values (500 μmol m^{-2} s^{-1} ≤ PAR ≤ 1 500 μmol m^{-2} s^{-1}). However, for high PAR values (≈ 2 000 μmol m^{-2} s^{-1}), those equivalent to a sunny day, the values of Φ_{PS2}, ETR, and q_P for both red and green leaves showed only minor differences despite the strong differences in their pigment composition [0.02 g(Chl) m^{-2} *versus* 0.20 g(Chl) m^{-2}].

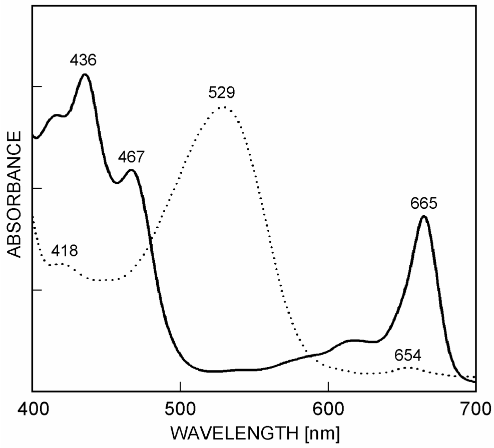

Fig. 1. Visible radiation absorption spectra of 80 % ethanol-extracts of green leaves (*full line*) and acetone/HCl-extracts of red leaves (*dotted line*) of poinsettia.

However, this is not the case for the q_{NP} values of red and green leaves (Fig. 2*D*), which diverge at increasing PAR. Furthermore, in the commonly assayed PAR range, q_{NP} values are always lower for red than for green leaves. Since high q_{NP} values are indicative of a high capacity to dissipate photon energy safely (Müller *et al.* 2001), the lower q_{NP} values shown by red leaves probably indicate that the redox machinery present in the chloroplast is insufficient to prevent the production of harmful species, such as singlet oxygen, which may be produced in the photosynthetic apparatus of red leaves under high irradiance. Thus, since red leaves show a low ability to dissipate excess photon energy safely (Fig. 2*D*), red

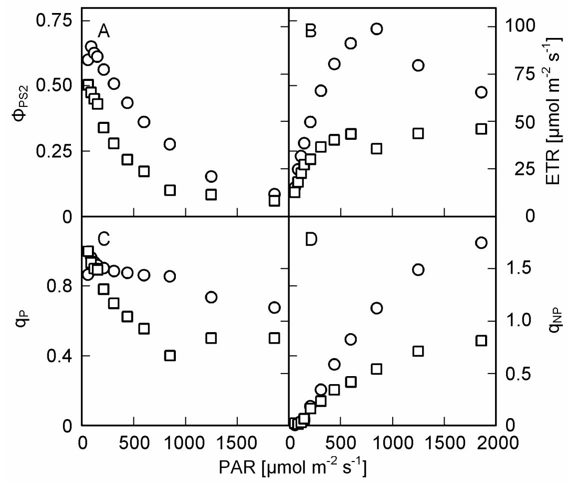

Fig. 2. Effect of varying PAR values on the quantum yield of photosystem 2, Φ_{PS2} (*A*), the linear electron transport rate ETR (*B*), and the photochemical, q_P (*C*) and non-photochemical, q_{NP} (*D*) quenching of chlorophylls, in green (*circles*) and red (*squares*) leaves of poinsettia measured at 25 ºC. Means ± SE (SE are hidden by symbols), *n* = 6.

leaves have developed the strategy of creating an optical red filter (Fig. 1) to reduce the amount of incident photons on the chloroplast. In this context, anthocyanins protect chloroplasts from photoinhibition at high PAR by intercepting high-energy green photons in the plant vacuole that would otherwise be absorbed by Chl *b* in chloroplasts (Gould *et al.* 1995), as it may be deduced from the observation that, unlike green leaves, red leaves do not show inhibition of ETR values at high irradiances (Fig. 2*B*).

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