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Photosynthesis in ripe strawberries (*Fragaria* × *ananassa*) recording by a MAXI IMAGING-PAM

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Abstract

The presence of functioning PS II in fruits (achenes) of strawberries is demonstrated using chlorophyll fluorescence imaging.

Introduction

The actual fruit portions of a strawberry are the achenes. Achenes are indehiscent fruits which are visible at the surface of the fruit carrier. The fruit carrier is derived from the receptacle which, during its development, changes from green to red coloration due to chlorophyll degradation and anthocyanin accumulation. The ripening of many fruits progresses in parallel with chlorophyll decay and, hence, loss of photosynthetic capacity (Matile *et al*. 1999). Strawberry achenes, however, often retain their green color which suggests incomplete chlorophyll decomposition and the presence of some photosynthetic capacity. Here we use chlorophyll fluorescence imaging to demonstrate that functioning PS II exists in strawberry achenes.

Material and methods

Plants and Instrumentation

Strawberries were obtained from the local market and acclimated to complete darkness for at least one hour. The Maxi version of an *IMAGING-PAM M-Series* (Walz, Effeltrich, Germany) was utilized to record fluorescence images. Modulated measuring light of 0.5 µmol·m^{-2}·s^{-1}, actinic light of 450 µmol·m^{-2}·s^{-1} and saturating flashes of 6000 µmol·m^{-2}·s^{-1} were delivered from an array of diodes which is optimized to produce homogeneous illumination at sample level. Fluorescence ratio images (Fig. 1B to D) are displayed in the "F_M-scaled color mode" which emphasizes fluorescence ratios associated with high absolute F_M intensities.

Chlorophyll fluorescence from achenes and sepals was selected by defining areas of interests (AOI) using the ImagingWin Software (Walz). Three types of PSII quantum yields were calculated (Genty *et al.* 1989; Kramer *et al.* 2004):

Y(II) effective photochemical quantum yield of PS II,

Y(NPQ) quantum yield of light-induced non-photochemical fluorescence quenching, and

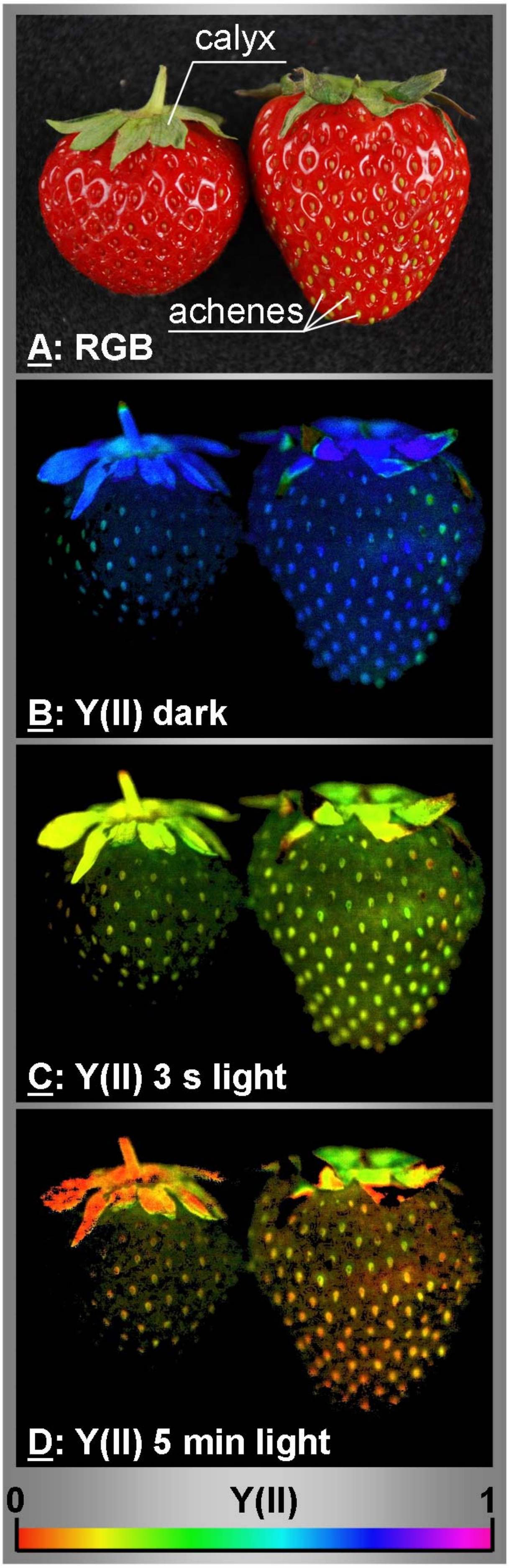

Fig. 1. Strawberry images taken with a RGB camera (A) and an IMAGING-PAM (B to D). The latter panels show images of Y(II) taken in the dark, and after 3 s and 5 min exposure to blue light of 450 µmol·m^{-2}·s^{-1}, respectively.

Y(NO) quantum yield of non-light-induced non-photochemical fluorescence quenching.

Results and discussion

High values for Y(II) were observed in dark-acclimated achenes and sepals (Fig. 2A) which indicate the presence of active PS II. After onset of actinic illumination, the Y(II) of both achenes and sepals dropped to values close to zero, recovered partially during further exposure to actinic light and approached initial values after the actinic light was switched off. The marked reduction in Y(II) suggests that absorbed light energy exceeds the current capacity for PS II charge separation.

Unlike Y(II), the type of energy dissipation during light exposure differed between achenes and sepals: energy dissipation *via* Y(NPQ) was clearly lower in the achenes than in the sepals (Fig. 2C): an inverse relationship was observed for the Y(NO) (Fig. 2B). Because the build-up of Y(NPQ) depends on the formation of a trans-thylakoid pH gradient, proton pumping appears to be inefficient in achenes and, consequently, formation of ATP to drive carbon assimilation seems to be impaired.

It has been suggested that photosynthesis in "green-ripe" fruits contributes meaningfully to the carbon balance of these organs (Cipollini and Levey 1991). Considering our fluorescence data, however, it is unclear if photosynthesis in strawberry achenes is capable to support seed development.

References

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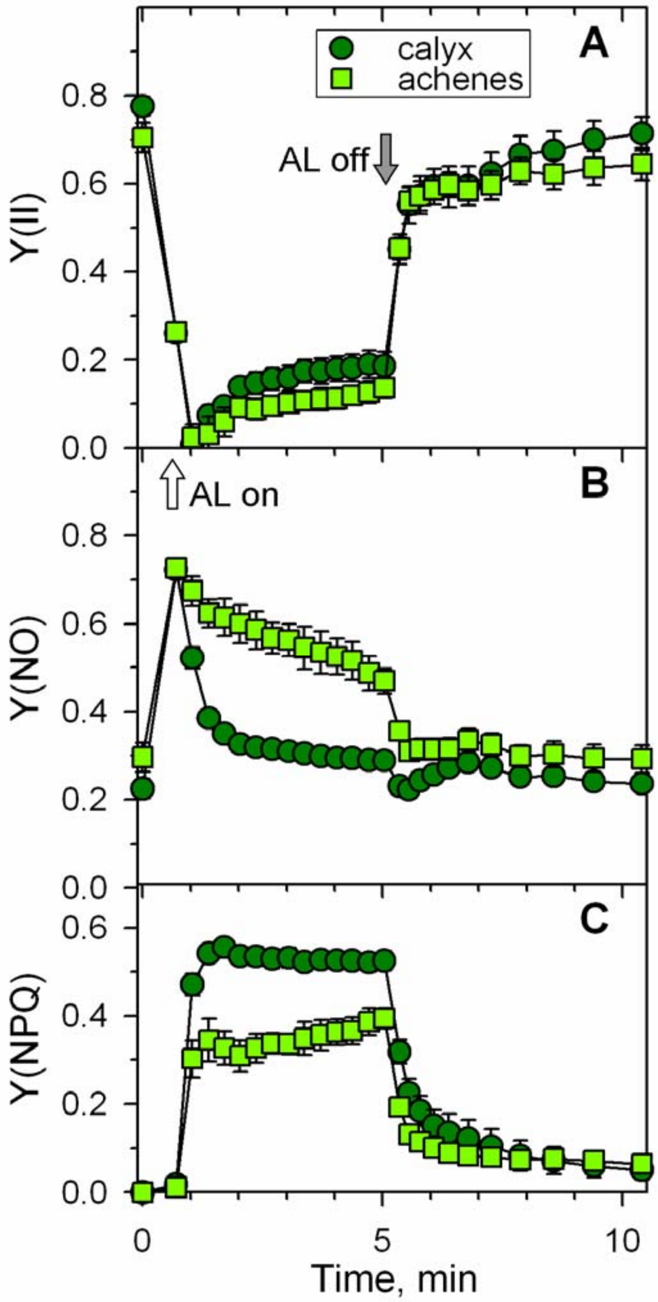

Fig. 2. PS II quantum yields in strawberry calyx and achenes during a dark-light-dark transition. Dark-acclimated strawberries were exposed to actinic light (AL) of 450 µmol·m^{-2}·s^{-1} for 5 min and, subsequently kept under dark conditions. A: yield of photochemical energy utilization, Y(II); B: yield of non-regulated energy dissipation, Y(NO); C: yield of regulated energy dissipation Y(NPQ). Data represent means of 4 and 7 measurements of sepals and achenes, respectively, of a single strawberry. Error Bars: standard deviation.