Induction kinetics of heat emission before and after photoinhibition in cotyledons of Raphanus sativus

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Abstract. Heat emitted during non-radiative de-excitation was determined in vivo by the photoacoustic method. The dependence of the photoacoustic signal on the length of the pulses (modulation frequency) of the excitation light and the effect of continuous light, which saturates photosynthesis but does not directly contribute to the signal, are described. The induction kinetic of heat emission measured with intact leaves differed only slightly from the induction kinetic of fluorescence (Kautsky effect) detected in parallel. The photoacoustic signal at high modulation frequencies (279 Hz), which represents the signal of heat emission, and the photoacoustic signal at low modulation frequencies (17 Hz), interpreted as a signal of pulsed oxygen evolution superimposed on the heat emission, were measured with leaves before and after photoinhibition. It was demonstrated that after photoinhibition the decrease in fluorescence yield and in photosynthetic activity (here detected as photoacoustic signal at 17 Hz) are paralleled by an increase in the yield of non-radiative de-excitation (photoacoustic signal at 279 Hz). The increase of heat emission, which has been hypothesized for photoinhibited leaves, could now be proved by measuring the induction kinetics of the photoacoustic signal.

Introduction

Heat emitted from a leaf tissue during non-radiative de-excitation represents part of the light energy taken up during light absorption. The energy of heat emission of the photosynthetic pigments is lost for photosynthesis just as the energy of the chlorophyll fluorescence (Buschmann et al. 1984, Butler 1978).

Since the work of Kautsky it is known that fluorescence emission of photosynthetic active plant material undergoes a transient, which is related to its rate of photosynthesis (Krause and Weis 1984). The induction kinetics of fluorescence (Kautsky effect) are already well understood, whereas only a few data are available about the induction kinetics of heat emission. A
transient of heat emission of a plant has been postulated as nonphotochemical loss of energy deduced from the fluorescence kinetic (Bradbury and Baker 1981, Krause et al. 1982, Schreiber et al. 1986). It is expressed as “energy quenching” detectable upon energization of the thylakoid membrane, which is closely related to the transthylakoidal pH-gradient (Briantais et al. 1980).

In this publication the induction kinetic of fluorescence and heat emission are described for photoinhibited leaves. Photoinhibition is defined as the reduction of photosynthetic capacity induced by illumination with light of intensities much higher than needed for photosynthetic light saturation (Osmond 1981, Powles 1984). It is well established that photoinhibition leads to a decreased electron transport, which is due to the loss of the function of the 32 kD protein (Kyle et al. 1984) and to photodamage of the PS II reaction center (Cleland et al. 1986). At the same time the fluorescence yield is lowered (Björkman and Powles 1984, Critchley and Smillie 1981, Lichtenthaler et al. 1983, Powles and Björkman 1982). The energy loss in a photoinhibited leaf has been interpreted as changes of energy distribution around PS II (Björkman and Powles 1984) or by an increase in the yield of heat emission (Critchley and Smillie 1981, Powles 1984, Powles and Björkman 1982). Up to now, heat emission has never been measured with photoinhibited leaves.

Here results are presented applying the photoacoustic method, which is at present the most sensitive technique for measuring heat emission (Buschmann and Prehn 1986, Buschmann et al. 1984, Malkin and Cahen 1979). Heat pulses induced by pulsed excitation light are measured using a microphone, which detects pressure changes caused by the extension of the heated gas above the sample. The system used for this investigation permits the measurement of induction kinetics of heat emission parallel to that of fluorescence and thus can give information about the distribution of energy during the de-excitation processes.

Materials and methods

Radish seedlings (Raphanus sativus L., cv. Saxa Treib) were grown for 2 weeks on peat. They were kept at 23 ± 3 °C and 60% relative humidity, illuminated with white light (fluorescent lamps, OSRAM “Fluora”, 50 μE·m−2·s−1) for 14 hours per day.

For the photoinhibition the hypocotyls of the seedlings were dipped into water with the roots removed. The cotyledons were exposed for 15 min to an