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Photoacoustic analysis of the ultrasonic irradiation effect in the photosynthetic activity in aquatic lirium plants

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ABSTRACT

We report, the application of the photoacoustic technique for monitoring the photosynthesis evolution in aquatic lirium (*Eichhornia Crassipes*), before and after it was exposed to ultrasonic irradiations. We obtained the disappearance of the phototobaric contribution in the PA signal measured for the irradiated samples with ultrasound of 17 kHz, and therefore of a possible damage in the centers producing the photosynthesis, due to the irradiation. These results show the utility of the ultrasonic irradiation, as well as, of the photosynthesis monitoring by means of the photoacoustic technique, for the elaboration and establishment of methodologies in the control of this aquatic plant, whose propagation causes many consequences extremely unfavorable for the environment, as well as for the diverse human activities that are developed in the bodies of water in the tropical and sub-tropical regions of the world.

1. Introduction

Aquatic Lirium, water hyacinth, is a free float plant native of the Amazon, Brazil, which by the beauty of its flowers has been propagated to almost all the tropical and sub-tropical regions of the world. This plant is a weed, which causes many consequences extremely unfavorable for the environment and for the diverse human activities that are developed in the bodies of water (Wright and Center, 1984; Smith et al., 1984). Among the most used methods to control water hyacinth, we will have the herbicides, physical removal or drainage, and biological control, none of which has been entirely efficient or profitable (Jamieson et al., 1977; Julien, 1992). Therefore, it is important to develop better methods for the control of this weed, technically effective, economically viable and environmentally friendly (Cardona, 2010).

It is for these reasons that arises the need to incorporate other new technologies of control, being in this case the use of ultrasonic irradiations, with certain values of frequency and intensity, in order to induce cavitation in the aqueous structure of the aquatic lirium, and consequently, inhibit their photosynthetic activity, causing its death.

When the powerful ultrasound (16–100 kHz) is applied to a liquid with enough intensity, the liquid undergoes a compression and expansion alternately forming bubbles that may contain steam from the more volatile components of liquid or gas dissolved in it. These bubbles have a very short lifetime, and when they collapse, appear so-called "hot spots" of high temperature and pressure that produces energy that causes damage on the surfaces (Kenneth and Suslick, 1988; Mason and Lorimer, 2002).

The leaves of aquatic plants are systems particularly useful for studying the effects of bubbles trapped within their structures. For this reason, in this work it was used the Photoacoustic (PA) technique as a function of time by monitoring the photosynthetic activity (Cardona et al., 2008; Da Silva et al., 1995; Barja et al., 2001; Mesquita et al., 2006) in aquatic lirium plants, without irradiation and after ultrasonic irradiation, showing that the photoacoustic technique provides an early detection of the damage caused by the ultrasound irradiations in water hyacinth plants.

2. Experimental

2.1. Samples

The plants of water hyacinth remained stable in the laboratory, inside an aquarium-greenhouse designed to simulate and monitor the conditions under which survives the hyacinth in their habitat of origin (Cuemánco channels, Mexico City). During this time, were controlled physiochemical parameters of water, the concentration of nutrients (provided through a liquid fertilizer), as well as the intensity and duration of illumination.

Table 1 summarizes the most convenient conditions that allowed the survival of plants in vivo and in situ. With regard to the concentration of nutrients it was used as an universal liquid fertilizer 15N-30P-15k (based on a hydroponic) with 61.34 g in a

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Table 1
Physicochemical parameters of control.

Parameter	Value
pH	6.05
Temperature	25 °C
Conductivity	477 μS/cm
Chlorine	0.5 mg/l
Light intensity	5000 lx
Lighting time	13 h/day

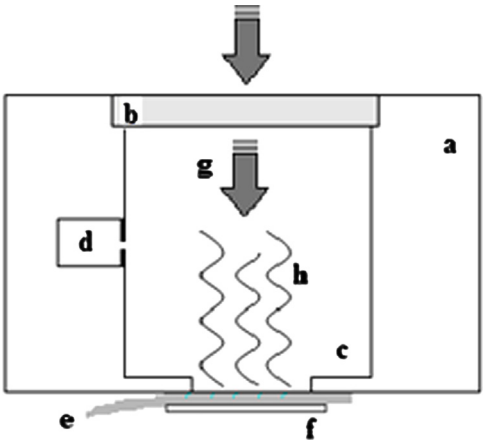

Fig. 1. Scheme of the PA cell: (a) body of the cell, (b) quartz window, (c) PA chamber, (d) acoustic detector, (e) sample (leaf of the plant), (f) flat backing of glass, (g) modulated light, (h) photothermal and photobaric response.

filling volume of 180 l. Using these parameters in the adaptation process, the plants showed a favorable physiological development. At the beginning were introduced 43 individual juvenile plants of hyacinth in an aquarium-greenhouse. The average dimensions of the plants were Leaf=5 cm, Petiole=10 cm, Root=11 cm, and were picked up from channels of Cuemánco, Mexico City. During 2 months the behavior of the plants was observed, in which did not occurs any type of necrosis, and besides, there were new outbreaks of stolon and development of more petioles.

The experimental measurements were realized at noon on a hyacinth plant taken from the aquarium-greenhouse and placed inside of a container filled with the same water of the aquarium-greenhouse. The PA measurement system was located 50 cm from the aquarium-greenhouse under similar conditions of temperature and lighting. Each experimental run lasted 210 s. After each measurement, was placed the plant again inside the aquarium-greenhouse.

2.2. Photoacoustic cell

Fig. 2 shows the scheme of the PA cell. The sample (a leaf of the plant) is placed at the base of the PA chamber using vacuum grease to adhere it, so that one side of the sample is in contact with air inside the PA chamber and the other is supported on a flat backing of glass that keeps it rigid and pressing on the base of the PA chamber.

When the modulated radiation passes through the quartz window falls in the face of the sample placed inside of the PA chamber (see Fig. 1), then the luminous energy absorbed by the leaf generates an acoustic signal inside the PA chamber that is detected by the

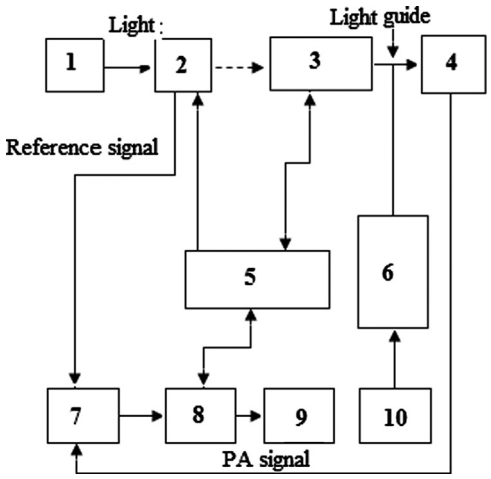

Fig. 2. Experimental setup of the PA technique as a function of time to measure photosynthetic rate: (1) xenon lamp, (2) chopper, (3) monochromator, (4) PA chamber+sample, (5) interphase, (6) IR filter, (7) lock-in amplifier, (8) computer, (9) graph, (10) continuous light from a QTH lamp.

acoustic transducer coupled to the cell. This acoustic signal consists of the superposition of the next two contributions:

1. The photothermal response, resulting from the conversion of part of the absorbed modulated light in modulated heat that diffuse towards inside the PA chamber to generate the acoustic signal.
2. The photobaric response, resulting from the variations in pressure within the chamber by the modulated oxygen produced in the photosynthetic process of the leaf.

2.3. Experimental setup

The experimental setup of the PA technique as a function of time for the measurement of photosynthesis in plants is given in Fig. 2. Here, the beam of continuous white light, coming from a xenon lamp, passes through a mechanical modulator (chopper), whose signal is in reference with the Lock-in amplifier; afterwards, the modulated emergent beam is made to pass through a monochromator, which selects the light wavelength which is chosen to work, in this case 680 nm. Then, the modulated monochromatic beam is leaded by means of an optical fiber to the PA chamber where the sample has been previously placed.

On the other hand, the continuous light from a QTH (quartz tungsten halogen) lamp is conduced to the PA chamber too. Both light beams simultaneously impinge on the sample, using for this a bifurcate optical fiber. Once the signal of the PA cell is obtained it is conduced towards the lock-in amplifier, which filters the signals that are not in the reference frequency and amplifies the signal coming from the PA Cell. All the systems are controlled by the computer. Finally, the amplitude and phase of the PA signal are registered and stored in the computer, as a function of time.

3. Results and discussion

Fig. 3 shows the so called “negative effect”, which is used to determine the photochemical activity of “in vivo” and “in situ” leaves. The behavior of the photobaric and photothermal contributions of the PA signal is measured as a function of time in hyacinth leaves before it were exposed to ultrasonic irradiations, with a fixed modulation frequency of 30, 50 and 70 Hz in each case. Here, when the background white light is applied, $t=30$ s (↑),