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HISTORY & BIOGRAPHY

Contributions by Christa Critchley to photosynthesis research and to plant ecophysiology

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Abstract

Christa Critchley is a distinguished researcher in basic and applied photosynthesis research. Her research has centered on the structure and function of chloroplasts and the application of chlorophyll *a* fluorescence to understanding the way PSII works. In her research, she used two biophysical tools, Nuclear Magnetic Resonance (NMR) and Chlorophyll (Chl) *a* fluorescence, as well as several other biochemical and plant physiological methods. Later in her career, she pioneered research in artificial photosynthesis (AP) focusing on the process of light-mediated water splitting and oxygen evolution. Here, only a glimpse of her life and some selected research is included.

Keywords: 12th International Congress on Photosynthesis; chlorophyll fluorescence; Nuclear Magnetic Resonance; photoinhibition; photosystem II; women in science.

Introduction

Christa was educated in Germany and completed her undergraduate degrees at the Albertus Magnus Universität in Cologne. After finishing her PhD in 1976 at the Heinrich Heine Universität in Düsseldorf, she took up a postdoctoral position at the Commonwealth Scientific and Industrial Research Organisation (CSIRO) in Sydney, Australia. From 1977 to 1980 she was a postdoctoral fellow at the Research School of Biological Sciences, Australian National University, Canberra. Then, she was a Research Associate in the Department of Chemistry at the University of Illinois at Urbana/Champaign from 1981 to 1982. She returned to Australia as a National Research Fellow, working in the Department of Botany from 1982 to 1987. From 1988 to 2002 she held several academic positions at the University of Queensland in Brisbane, Australia, and became Head of the Department of Botany in 2001. From 2002 to her retirement in 2009 she served as Deputy Dean and then Dean of the University of Queensland Graduate School. She is now Professor Emerita at the University of Queensland.

Christa Critchley's academic and community service activities have included her being president or secretary of several Australian scientific societies and a member of international scientific societies. She organized the 12th International Congress on Photosynthesis Research in Brisbane in 2001 (*see* Fig. 1; for history and photographs of these conferences, *see* Govindjee and Yoo 2007).

Christa has also served as an external examiner for Nanyang Technological University, Singapore, an inaugural member of the Australian Research Council (ARC) Research Training and Careers Committee, and co-founder of *WISENET* (Women in Science Enquiry Network). From 2011 to 2012 she was a consultant to Laureate Education Asia, establishing a new university in Australia, now known as Torrens University. She is a Fellow of the Queensland Academy of Arts & Sciences.

Highlights

- Christa Critchley is a highly original plant molecular, physiological, and ecological biologist
- She is a pioneer in understanding the role of light and ions in plant function
- She has contributed extensively to education and the cause of women scientists

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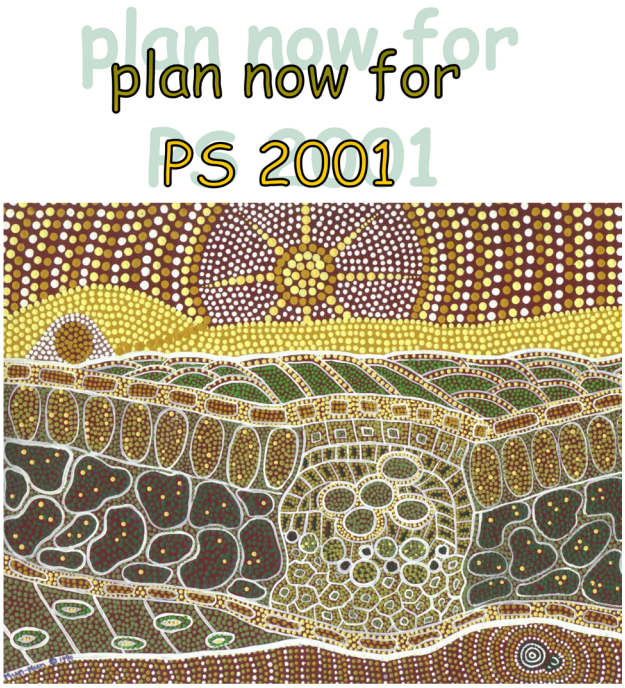

Fig. 1. A photograph of the emblem for the 12th International Congress on Photosynthesis Research. The title of the painting was '**The Mourning Sun**' (*Sun as a distraught mother looking for her child*, according to one ancient culture). Christa Critchley had shown the artist Mun Mun (Ramona Cavanagh) a leaf cross section with stomata on the underside (*see the lower left*) with chloroplasts in mesophyll cells and the vascular architecture of the mid rib. Grasping the totality of the photosynthetic apparatus from leaf cells to the environment, the artist had used her traditional dot painting technique to translate the upper epidermis into fields of green (*middle*), and golden grain under the rising sun in the distance (*top*). Thus, this artist linked our search into solar energy transduction in photosynthesis to the legend of a mother (*left horizon*) in search of her lost child (*lower right*). This remarkable work of art is a tribute to Christa Critchley's ability to enthuse everyone about photosynthesis research. Source: Barry Osmond.

Christa's contribution to education has included two edited books (Smith *et al*. 2004, Collings and Critchley 2005), the first one dealing with photosynthetic adaptation and the second one with artificial photosynthesis, key topics of the day.

Research

Revealing the function of chloride and using Nuclear Magnetic Resonance (NMR)

Most of the time Christa spent in Govindjee's laboratory at UIUC (https://www.life.illinois.edu/govindjee/) involved examining the role of chloride in oxygen evolution using a novel way of measuring it by NMR in Professor Herbert S. Gutowsky's laboratory. Professor Gutowsky was a world leader in NMR (*see*: https://chemistry.illinois.edu/spotlight/faculty/gutowsky-herbert-s-1919-2000) and Dr. Ion C. Baianu was the collaborator who had come to Gutowsky's Lab from Romania [for Baianu (1947–2013), *see* Brown and Glazebrook 2013].

Using thylakoids from leaves of salt-tolerant plants such as mangroves, Critchley *et al*. (1982) established the requirement for >250 mM chloride ions for maximal electron transport activity in these thylakoids; she also showed that Ca^{2+} was a much better cation than Mg^{2+}, K^+, or Na^+ and that this combination indeed works on the water oxidation side of PSII. Her key contribution was the evidence, established through ^{35}Cl NMR measurements, that chloride and calcium function on the electron donor side of PSII. This research was followed by comparing salt-tolerant with non-salt-tolerant plants such as spinach (Baianu *et al*. 1984). Here, Critchley found that there were two types of Cl-binding through Cl-NMR line broadening. She also actively participated in ongoing physiological studies in the laboratory of William Ogren (for one of the many articles honoring Ogren, *see* Portis and Govindjee 2012) on the effects of CO_2 concentration on the growth and electron transport function of the green alga *Chlamydomonas reinhardtii* (*see* Spalding *et al*. 1984).

Interestingly, in 2004, when she was in Australia, Critchley went back to using NMR. She examined Na^+ ions by microimaging the samples (Rokitta *et al*. 2004). To understand the physiological basis of the adaptation of salt-tolerant plants to high sodium concentrations, she (with her coworkers) used ^{23}Na NMR at high resolution and combined it with proton (^1H) NMR measurements, the latter providing new information on water distribution in stem slices. Results from this study clearly showed that ^{23}Na NMR microimaging is a potentially unique tool to diagnose salinity tolerance in plant tissues. We urge plant scientists to include this novel tool in their future research.

Developing chlorophyll *a* fluorescence to understand plant function

Chlorophyll (Chl) *a* fluorescence measurement provides a highly sensitive non-invasive method for monitoring the 'health' of plants (*see e.g.*, Govindjee 1995 for a historical perspective on Chl *a* fluorescence). As have many others, Critchley used this biophysical tool on plant leaves in the laboratory and the field once portable instruments became available. (*Heinz Walz GmbH* – Walz Photosynthesis Instruments, https://www.walz.com). Her outstanding research in this area is summarized below.

Photoinhibition (PI) is a serious problem because excess irradiance damages photosynthetic systems. In Leitsch *et al*. (1994), Critchley measured PI through a decrease in variable (F_v) to maximal (F_m) Chl *a* fluorescence. The F_v/F_m ratio has been shown to be an indicator of the quantum yield of PSII. Critchley and coworkers studied PI under many different conditions (temperatures, light intensities, gas conditions, with and without antibiotic streptomycin). Based on all the data,

she and her coauthors suggested that there are two steps in the process of photoinactivation of PSII: a fast one where reactivation occurs under low light without the turnover of the D1 protein, and a slower one involving oxygen, where the D1 protein of PSII is affected and where the reactivation process requires the removal and replacement of this protein.

Critchley and Russell (1994) reviewed the various models proposed for the mechanism of photoinhibition in higher as well as lower plants. They suggested a novel model where PSII operates under a feedback control mechanism involving both light and dark reactions and depending not only on the available light but also on the biochemical demand of carbon fixation.

In Dodd *et al.* (1998), Critchley continued her interest in understanding photoinhibition not only in leaves but in other physiological aspects of plant function, *e.g.*, the age and the position of leaves in the canopy, development status or diurnal changes, all by measuring the F_v/F_m ratio *in vivo*. This study had centered not only on dark green (*Syzygium moorei*), and light green (*Syzygium corynanthum*) leaves but also on pink-red (*Syzygium wilsonii*) leaves. I recommend this paper to all students of physiological ecology to see how Chl *a* fluorescence can be used to understand plants under different conditions in their natural environment.

White and Critchley (1999) extended this Chl *a* fluorescence work to monitor the physiological status of *Pisum sativum* (peas) with a novel method known as 'Rapid Light Curves' using a new portable Chl fluorescence instrument (*see* https://www.walz.com) under different conditions: very low to very high light intensity; varying time of illumination and time of dark adaptation; and different histories of long-term growth illumination, White and Critchley identified different adaptation mechanisms under different treatments. Then, Force *et al.* (2003) used the Chl *a* fluorescence OJIP transient, where 'O' is the minimum fluorescence as the measurement begins on a dark-adapted sample exposed to bright light, 'P' is the peak (maximum) fluorescence, and 'J' and 'I' are intermediate inflections in between. This 'JIP' test was applied by Force *et al*. on isolated PSII systems from both atrazine-resistant and sensitive *Chenopodium album.* They then applied this information to understand the intact, *in situ* system. They also examined the JIP transient during photoinhibition and concluded from their thorough analysis that the probability of electron transport is greatly decreased and that dissipation as heat is significantly increased in photoinhibited samples.

Thach *et al*. (2007) studied plant rarity, also using Chl *a* fluorescence. They chose *Graptophyllum reticulatum*, an endangered endemic species, and its three relatives with different conservation status: *G. ilicifolium* (vulnerable), *G. excelsum* (rare), and *G. spinigerum* (common). Thach *et al*. showed that soil type was of no importance but that photoinhibition was probably keeping the endangered *G. reticulatum* to shade habitats. The availability of water also played a role in the distribution of *G. ilicifolium* and *G. spinigerum* in their natural habitats. No obvious relationship was found between the conservation status and the environmental resilience although rarity may develop by changes in the environment which then, in turn, affects the distribution of species with conservation significance.

I end this honor to Christa Critchley with her photograph (*see* Fig. 2) with me and with David (Dave) Knaff. For Knaff (1941–2016), *see* Malkin (2016).

Fig. 2. *Left to right*: G. Govindjee, Christa Critchley, and David Knaff at a late 1980s Gordon Conference on Photosynthesis. Source: Personal collection of G. Govindjee.

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