Journal of Plant Physiology 231 (2018) 9–18

Contents lists available at ScienceDirect

Journal of Plant Physiology

journal homepage: www.elsevier.com/locate/jplph

Effects of weak static magnetic fields on the gene expression of seedlings of *Arabidopsis thaliana*

Sunil K. Dhiman[a,b], Paul Galland[a,*]

[a] Faculty of Biology, Philipps-University Marburg, Karl-von-Frisch-Str. 8, D-35032 Marburg, Germany
[b] Kirori Mal College, Delhi University (North Campus), Delhi-110007, India

ARTICLE INFO

Keywords:
Arabidopsis
Cryptochrome
Static magnetic field
Magnetoreception
Magnetic field reversal
Radical-pair mechanism
Stimulus-response relationships

ABSTRACT

Magnetic-field reception of animals and plants is currently discussed in the framework of a cryptochrome-based radical-pair mechanism. Efforts to unravel magnetoreception in plants suffered historically from several shortcomings, most prominently, the conspicuous absence of detailed stimulus-response relationships. To determine the sensitivity of seedlings of *Arabidopsis thaliana* to weak static magnetic fields we generated stimulus-response curves between near zero and 188 µT for the transcript levels of the genes *rbcl*, *cab4*, *pal4* and *ef1*. The moderate magneto-responsiveness of dark-grown seedlings was greatly enhanced under blue light, and for *rbcl* and *pal4* also under red light. The stimulus-response curves obtained under blue light of constant photon-fluence rate displayed multiple maxima and thus a pattern fundamentally different from that prevalent in plant and animal physiology. A double mutant lacking cryptochromes 1 and 2 displayed altered stimulus-response curves without losing, however, magneto-responsiveness completely. A reversal of the magnetic field direction substantially affected the gene expression and the quantity of CAB-protein (chlorophyll *a*,*b*-binding protein). The majority of our results are at variance with the notion of cryptochromes acting as the only magnetic-field sensors. They do not, however, exclude the possibility that cryptochromes participate in the magnetic field reception of *Arabidopsis*. The findings have the unexpected implication that cryptochrome- and phytochrome-mediated plant responses can be modulated by the strength and the orientation of the local geomagnetic field.

1. Introduction

Paleogeological records indicate that the geomagnetic field (GMF) existed for at least 4.2 billion years (Tarduno et al., 2015), a period during which it underwent reversals approximately every 10^6 years (Juarez and Tauxe, 2000). Field reversals are preceded by a period of several thousand years during which the magnetic field (MF) may drop to some 5 µT (Juarez et al., 1998), i.e. well below the present field strength. During Earth's history organisms have thus been exposed to a rather narrow field range that extends presently from about 25 to 65 µT (Finlay et al., 2010), and it is thus pertinent to ask, if such weak fields are able to affect fundamental aspects of life. During the past decades magnetobiology has witnessed great progress in elucidating various mechanisms of MF orientation such as those of magnetotactic bacteria (Bazylinsky and Frankel, 2004), insects (Gegear et al., 2008; Fedele et al., 2014; Giachello et al., 2016) and migrating birds (Liedvogel and Mouritsen, 2010; Möller et al., 2004; Wiltschko and Wiltschko, 2012). The physical principles underlying the phenomena of MF orientation of insects and birds are currently approached in the framework of a cryptochrome-based radical-pair mechanism (RPM, see below) (Lee et al., 2014; Ritz et al., 2000; Rodgers and Hore, 2009; Solov'yov and Schulten, 2009).

The question whether or not weak static MFs influence organisms also in other ways, such as affecting developmental or biosynthetic pathways, has been investigated less rigorously. Despite numerous investigations purporting the ability of eukaryotes to respond to static fields, the research, particularly in plant science, has remained somewhat rudimentary until 2005 (Galland and Pazur, 2005), but has taken a positive turn during the past decade with the employement of *Arabidopsis thaliana* as a model organism to unravel the mechanisms of plant magnetoreception (Maffei, 2014; Occhipinti et al., 2014). Initially, recent investigations focussed on developmental responses such as hypocotyl elongation and flower formation. While hypocotyl elongation was found to be only moderately responding to MFs during the first 120 h after seed germination (Ahmad et al., 2007), other authors could identify larger MF effects for exposure times exceeding 120 h

Abbreviations: MF, magnetic field; GMF, geomagnetic field; RPM, radical-pair mechanism

* Corresponding author.
E-mail addresses: sukudhiman0206@gmail.com (S.K. Dhiman), galland@staff.uni-marburg.de (P. Galland).

https://doi.org/10.1016/j.jplph.2018.08.016
Received 16 June 2018; Received in revised form 26 August 2018; Accepted 29 August 2018
Available online 03 September 2018