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Effects of electricity on plant responses

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ABSTRACT

Numerous investigations into the abiotic elicitation of plant responses with UV-B radiation, temperature, drought, CO_2, nutrients, heavy metals and wounding have been carried out in the agronomic sector and are described in various reviews. However, it is not clear if electricity can be classified as an abiotic stress elicitor to affect plants. While the aforementioned abiotic stress elicitors are well investigated, the impact of electricity on plant development and accumulation of metabolites is not well understood. This review describes the effects of electricity, including strong and weak electric fields, magnetic fields and electric currents on plant growth and development, as well as on plant metabolites. Possible signalling pathways as affected by electricity are also discussed. It is further discussed the application of electricity to enhance plants in horticulture and it's classification as an abiotic stress elicitor.

1. Introduction

Elicitors are agents that induce plant defence responses, for example, the accumulation of secondary plant compounds to re-establish a new state of homeostasis (Wu and Lin, 2002). Generally, stress elicitors are classified as either biotic or abiotic. Biotic stress elicitors have biological origin and are derived from pathogens (e.g., fungi homogenate and yeast extract) or from the plant itself (e.g., jasmonic acid and salicylic acid) (Gundlach et al., 1992; Sanchez-Sampedro et al., 2005; Soylu et al., 2002; Vasconsuelo and Boland, 2007; Yang et al., 2004). In contrast, abiotic stress elicitors do not have a biological origin, e.g., UV-B radiation, temperature, drought, CO_2, macro- and micronutrients, heavy metals, wounding and grafting (Giorgi et al., 2005; Vasconsuelo and Boland, 2007). In an effort to develop our basic knowledge of plant metabolism, numerous investigations into the effects of abiotic stress elicitors on plant responses have been carried out in the agronomic sector and are described in various reviews (De Pascual-Teresa and Sanchez-Ballesta et al., 2008; Martinez-Ballesta et al., 2008; Poiroux-Gonord et al., 2010; Treutter, 2010).

While the aforementioned abiotic stress elicitors are well investigated, investigations in terms of the effects of electricity on plant responses are still limited. In this context, electricity is the physical generic term for all phenomena associated with electric charge, such as lightning or the force action of magnetism. The term electricity is not sharply defined in the natural sciences, though specific properties belong to the core area of electricity. Electric fields, for example, are caused by electric charges and can occur, e.g., under high-voltage lines (Feynman et al., 1964). The SI units are newtons per coulomb or, equivalently volts per metre (V/m). Electricity also includes the electric current, which is a flow of electric charge carried by moving electrons in conductors or semiconductors or by ions in an electrolyte and is measured in ampere (A) (Horowitz and Hill, 2015). Direct electric current (DC) means that there is a unidirectional flow of electric charge, or a system in which the movement of electric charge is directed in only one direction. In contrast, the movement of electric charge periodically reverses its direction in alternating electric current (AC) systems. Magnetic fields also belong to the term electricity and are the magnetic effects caused by magnetic materials (e.g., permanent magnet), electric currents (e.g., when currents flowing through a coil) or temporal changes of an electric field. A magnetic field is usually measured in terms of its magnetic flux density whose unit is expressed as Tesla (T). Arguably the most important magnetic field is the Earth's magnetic field, also called geomagnetic field witch has magnetic flux density on the order of 50 μT (Kobayashi et al., 2004). Although the geomagnetic field, for example, is steadily acting on living systems and is known to effect many biological processes (Maffei, 2014), it is not clear if magnetic fields, electric fields and electric currents can be classified as abiotic stress elicitors to affect plants. Therefore, the present review will discuss aspects regarding plant growth and development, synthesised metabolites and possible signalling pathways as affected by electricity.

2. Effects of strong electric fields and magnetic fields on plants

2.1. Plant responses caused by strong electric fields

Although experimental details often were incomplete, positive

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Table 1
Plant responses caused by strong electric and magnetic fields.

Plant species	Treated plant organ	Treatment conditions	Effects*	Reference
Abelmoschus esculentus	Seeds	99 mT, 3 min	Germination rate (+) Plant growth (+) Yield (+)	Naz et al. (2012)
Apium graveolens	Plant	3.5–136 mT magnetized water, irrigated 158 d	Yield (+) Water uptake (+)	Maheshwari and Grewal (2009)
Avena sativa	Plant	40 kV/m, 2 m above the crop	Yield (+)	Blackman (1924)
Beta vulgaris	Seeds	5 mT, 16 Hz, 2 h	Root weight (+) Leaf yield (+)	Rochalska (2008)
	Seeds	5 mT, 16 Hz, 2 h	Chlorophyll (+) Nitrogen(+)	Rochalska (2005)
Brassica napus	Seeds	10 mT, 15 min	Plant growth (−) Fresh weight (−) Dry weight (−)	Shabrangi et al. (2010)
Cicer arietinum	Seeds	200 mT. 2 h	Germination rate (+) Seedling length (+) Root length (+) Root surface area (+) Root volume (+) Seedling dry weight (+)	Vashisth and Nagarajan (2008)
Cryptotaenia japonica	Seeds	0.75 mT, 7 Hz, 16 d	Germination rate (+)	Kobayashi et al. (2004)
Fragaria ananassa	Plant	0.096 T, 50 Hz, applied during growth 0.192, 0.384, 50 Hz, applied during growth	Fruit yield (+) Ca, Mg (+) Fruit number (−) Fruit yield (−)	Esitken and Turan (2004)
Glycine max	Seeds	150 mT, 250 mT, 60 min	Seedling length (+) Seedling fresh weight (+) Seedling dry weight (+) Photosynthesis (+) Water uptake (+)	Shine et al. (2011)
	Seeds	1500 nT, 10 Hz, 5 d	Catalase (+)	Radhakrishnan and Kumari (2012)
Helianthus annuus	Seeds	200 mT, 2 h	Germination rate (+) Seedling length (+) Root length (+) Root surface area (+) Root volume (+) Seedling dry weight (+)	Vashisth and Nagarajan (2010)
	Seeds	15 mT, 2 h	Chlorophyll (+)	Turker et al. (2007)
Hordeum vulgare	Plant	10 kV/m	Yield (+)	Lemström (1904)
	Seedling	125 mT, 1 min–24 h	Seedling length (+) Seedling weight (+)	Martinez et al. (2000)
	Seeds	100 kV/m	Germination rate (+)	Lynikiene and Pozeliene (2003)
Lactuca sativa	Seeds	18–105 kV/m, 60 Hz	Germination rate (+)	Zhang and Hashinaga (1997)
Leymus chinensis	Seeds	200 mT, 10 min	Plant growth (+) Peroxidase (+)	Xia and Guo (2000)
Linum usitatissimum	Plant	Magnetized water without specification, 55 d, irrigated twice per week	Plant development (+) Chlorophyll *a* (+) Chlorophyll *b* (+) Total indole acetic acid (+) Total phenolics (+)	Qados and Hozayn (2010)
Phaseolus vulgaris	Seeds	7 mT, 7 d	Germination rate (0) Plant growth (0) Root dry weight (0) Shoot dry weight (0)	Cakmak et al. (2010)
	Seeds	1.8 mT, 30 min/d, 10 d	Germination rate (−) Plant growth (−) Chlorophyll (−) Flavonoids (−)	Najafi et al. (2013)
	Plant	130 mT permanent	Plant growth (0) Leaf height (0) Gluthatione peroxidase (+)	Mroczek-Zdyrska et al. (2016)
Pisum sativum	Seeds	250 mT, 1 min – 24 h	Seedling length (+)	Carbonell et al. (2011)
	Seedling	1500 μT, 15 min	Superoxide dismutase (+)	Polovinkina et al. (2011)
	Plant	3.5 – 136 mT magnetized water, irrigated 143 d	Yield (+) Water uptake (+)	Maheshwari and Grewal (2009)
Raphanus sativus	Seeds	18–105 kV/m, 60 Hz	Germination rate (+)	Zhang and Hashinaga (1997)
	Seeds	5 mT, 60 Hz, 21 d	Germination period (−) Plant growth (+) Plant height (+)	Smith et al. (1993)
	Seedling	650 μT 185 – 325 μT	Catalase (+) Superoxide dismutase (+) Catalase (−) Superoxide dismutase (−)	Serdyukov and Novitskii (2013)

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