

# Signaling and Communication in Plants

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# Long-Distance Systemic Signaling and Communication in Plants

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# Preface

Higher plants coordinate and integrate their tissues and organs via diverse long-distance signalling and communication circuits. Sophisticated sensory systems sensitively screen both internal and external factors and feed sensory information into chemical and physical systemic long-distance communication cascades. Obviously, our view of plants is changing dramatically. We realize that their long-distance signalling is fast, and signals, both of endogenous and exogenous origin, spread rapidly throughout their bodies. This recent revolution in our understanding of higher plants started more than 40 years ago with the discovery of alarm peptide hormone systemin (Green and Ryan 1972; Ryan and Pearce 2003) and continues with rapid advances further. This volume of the ‘Signalling and Communication in Plants’ series captures the current dynamic ‘state of the art’ of this very exciting topic of plant sciences.

In general, there are chemical and physical mechanisms for the long-distance signalling and communication in plants. With respect to chemical communication, the most advanced topics are systemic acquired resistance (SAR), which is an inducible defence syndrome based on salicylic acid signalling (Ross 1966; Sticher et al. 1997; Chaturvedi et al. 2012; Wu et al. 2012), and systemic acquired acclimation (SAA), which is systemic signalling of photo-oxidative stress (Karpinski et al. 1999; Karpinski and Szechynska-Hebda 2010). Both SAR and SAA include several aspects of plant memory and anticipation of future insults via the memorized sensory perceptions, using quantum computing including quantum-redox sensing (Szechynska-Hebda et al. 2010; Karpinski and Szechynska-Hebda 2010). Importantly in this respect, both SAR and SAA are based on ROS and hormonal signalling pathways, but also include very rapid electrical and mechanical long-distance signalling. Another extensively investigated and well-understood topic is the long-distance wound signalling based on the alarm peptide hormone systemin and oxylipin-derived jasmonic acid (Farmer and Ryan 1990; Ryan and Pearce 2003, Sun et al. 2011). The next long-distance system is induced systemic resistance (ISR), which is induced by diverse non-pathogenic agents such as growth-promoting rhizobacteria and other plant beneficial microorganisms (van Wees et al. 2000; Rudrappa et al. 2010; Berendsen et al. 2012; Lee et al. 2012).

The nature of root-to-shoot long-distance communication is still not well understood for the ISR, but besides salicylic acid and jasmonic acid, abscisic acid is also involved (Kumar et al. 2012; Sampath Kumar and Bais 2012). Root-to-shoot long distance is also involved in the initiation and control of the symbiotic Rhizobia bacteria interactions with legume roots via so-called social media pathway (Venkateshwaran et al. 2013). Interestingly, this ‘social media’ pathway is also supporting long-distance interactions between roots and arbuscular mycorrhizal fungi (Venkateshwaran et al. 2013), which help plants to acquire nutrients, especially phosphate, and solutes. Last but not least, phosphate and iron homeostasis in plants is also safeguarded via long-distance signalling pathways and circuits (Enomoto et al. 2007; Enomoto and Goto 2008; Nagarajan et al. 2011; Smith et al. 2011).

Physical mechanisms of long-distance signalling and communication in plants include both electrical and mechanical/hydraulic mechanisms. In fact, electrical signals were discovered in plants more than 140 years ago (Burdon-Sanderson 1873, 1899; Stahlberg 2006). Although the plant action potentials show the same bioelectric parameters like animal/humans action potentials, they are driven by slightly different ion channels and other molecules (Fromm and Lautner 2007; Hedrich 2012; Baluška and Mancuso 2013). Despite this long tradition in plant electrophysiology, the importance and roles of plant action potentials for plant physiology and plant behaviour are still rudimentary (Brenner et al. 2006). However, it emerges that electric long-distance signalling in plants is more complex than that in animals because it includes also variation potentials, system potentials, and hydraulic signals (Malone 1992; Stahlberg 2006; Stahlberg et al. 2005; Zimmermann et al. 2009). It is also obvious that root apices and phloem represent the most active sites of electric activity in plants (Masi et al. 2006; Fromm and Bauer 1994; Fromm and Lautner 2007; Baluška and Mancuso 2013).

Another important and relatively well-understood topic in plant long-distance signalling and communication is that of mobile RNA molecules that move within the phloem (Lucas et al. 2001; Banerjee et al. 2006, 2009). Besides coding mRNAs, also non-coding regulatory RNAs are moving within plants (Schwab et al. 2009; Molnar et al. 2011), which is related to systemic propagation of the acquired stress-induced epigenetic changes (Molnar et al. 2011). For example, systemic acquired silencing (SAS) is rather a well-understood phenomenon studied in plants for more than a decade (Palauqui et al. 1997). Phloem elements are really unique as they represent supracellular highways for plant long-distance signalling, spanning throughout the whole plant body—integrating it into functional unity, using all kinds of diverse long-distance signalling and communication pathways (Lucas et al. 2001; Van Bel and Hafke 2013).

The final chapter of this volume is devoted to the emerging topic of long-distance signalling and communication in plants: herbivore-induced volatile organic compounds (VOCs) that act as semiochemical signals, playing roles in both the within-plant and plant–plant communication (Baldwin et al. 2006; Girón-Calva et al. 2012; Rodríguez-Saona et al. 2013). One important aspect of this new and important topic is the ability of VOCs to prime defenses in plants by enhancing

their resistance and responses to subsequent herbivore attacks (Kobayashi et al. 2006; Ton et al. 2007; Verheggen et al. 2010). Importantly, this long-distance signalling and communication via phytosemiochemicals has great potency for improving crop protection and efficiency of agriculture (Bruce 2010; Jansen et al. 2010; Khan et al. 2010).

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