Nutritional Endosymbiotic Systems in Plants: Bacteria Function like ‘Quasi-Organelles’ to Convert Atmospheric Nitrogen into Plant Nutrients

James F White Jr**, Holly Johnson1, Mónica S Torres1 and Ivelisse Irisarri1

1Department of Plant Biology and Pathology, Rutgers University, New Brunswick, New Jersey, USA
2Department of Engineering Technologies, Safety and Construction, Central Washington University, Ellensburg, Washington, USA

We propose that most plants are inhabited by nitrogen-fixing endosymbiotic bacteria whose hosts eventually degrade them through oxidation to extract nitrogen-containing nutrients. Such bacteria comprise the ‘nutritional endosymbiotic systems’ of plants thus enabling them to obtain critical nutrients for growth and development. It is already well known that endophytic microbes, both prokaryotic and eukaryotic, systemically inhabit plants [1-6]. Numerous studies of the diversity of endophytic microbes in plants suggest that these microbes are diverse enough and occur in high enough numbers as to constitute communities [4,7,8]. The number of microbes in plants further suggests that they may be biologically important to plant functions. However, we still know little about the roles that endophytic microbes play in enabling plant growth and development. Several hypotheses, all of which are based on supportive evidence, have been proposed that pose functional ecological roles for endophytes. These hypotheses include, but are not limited to, the following: defensive mutualism; plant growth promotion; stress protection; oxidative stress protection; habitat adaptation; and associative nitrogen fixation [1,2,9-19]. But, none of these hypotheses provide a sufficient mechanistic understanding of how endosymbiotic microbes benefit their host plants.

One critical function about which there is a dearth of mechanistic knowledge is the role which microbial endosymbionts play in aiding plants to acquire nutrients. Acquisition of nutrients, particularly nitrogen, is critical for plants to grow and develop. Moreover, its presence is frequently limited in soils. Plants are, however, immersed universally and for such a long time that one might consider it to be a ‘central dogma’ of plant ecology [20]. Yet, many plants (e.g., desert cacti and agaves, and epiphytic orchids, epiphytic ferns and epiphytic bromeliads) grow in circumstances (e.g. low water, low nutrient environments) where they cannot absorb nitrates from soils, and yet they manage to thrive [21,22]. We propose that exceptions, like the above-mentioned plants, demonstrate that the accepted model of nitrogen absorption predominantly from soils is not correct. We also posit that plants have not evolved their own nitrogenases because they already possess nutritional endosymbiotic systems involving nitrogen-fixing proteobacteria that function as ‘quasi-organelles’ to provide them with critical forms of nitrogenous compounds [1,12,23]. We further hypothesize that many plants obtain the majority of the nitrogen they require from endosymbiotic microbes and only a portion from soil nitrates.

Recently, we published evidence that certain grasses possess the capacity to extract nutrients from symbiotic nitrogen-fixing proteobacteria through a process of oxidation [24]. We termed this process ‘Oxidative Nitrogen Scavenging’ (ONS). Paungfoo-Lonhienne et al. [25] presented evidence that some plants appear to phagocytize bacteria as a nutrient source. We have additional unpublished data that many additional plant species possess ONS systems involving intracellular proteobacteria that are digested/oxidized in the process of plant development (Figure 1). The endosymbiotic bacteria that we encountered in plants are seed-transmitted and robust, in that they survive periods of seed storage. It is logical that these microbes are part of the nutritional endosymbiotic systems employed by plants. Likely, these systems provide developing plants with oligopeptides, amino acids, vitamins, nucleic acids, that not only contain nitrogen but that may serve as the building blocks of essential plant molecules. It is likely that all plants may obtain some nutrients directly from microbes at some point in plant development.

Nutritional endosymbiotic systems have been largely unstudied partly because the presence of the endosymbiotic microbes in healthy plants has gone unnoticed due to their small sizes. Further, many of the microbes involved are not easily cultured. It is also frequently

Figure 1: Oxidizing bacteria (Pantoea sp.; arrows) within a root hair cell of a seedling of rapeseed (Brassica napus), showing bacterial cells in vesicles surrounded by red-staining H2O2 (arrows; stained with 3.3’-Diaminobenzidine/horseradish peroxidase that counterstained with 0.1% aniline blue/lactic acid). Later stages of oxidation are indicated with white arrows.

**Corresponding author: James F White Jr, Department of Plant Biology and Pathology, Rutgers University, New Brunswick, New Jersey, USA, E-mail: white@aesop.rutgers.edu, jwhite3728@gmail.com

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difficult to identify plants that are free of the proteobacteria in order to conduct controlled experiments. The challenge to biologists studying these systems is to design studies to measure the extent to which plants obtain nutrients through digestion/oxidation of endosymbiotic microbes and to identify precisely what nutrients plants obtain from the microbes. Gaining an understanding of the nutritional functions of endosymbiotic microbes in enabling plant growth and development will change our understanding of how microbes and plants interact, how nitrogen flows in ecosystems and how plants have evolved.

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References