

1

Plant Defense

The innate immune system of plants protects them from adverse environmental conditions (biotic and abiotic stress). Regarding biotic stress (microbial infections), microbe-associated pathogen-specific molecules such as lipopolysaccharides (LPS) are recognized by pattern recognition receptors (PRRs) in the plant cell. This interaction results in the activation of multiple signaling processes, such as the production of effector molecules.

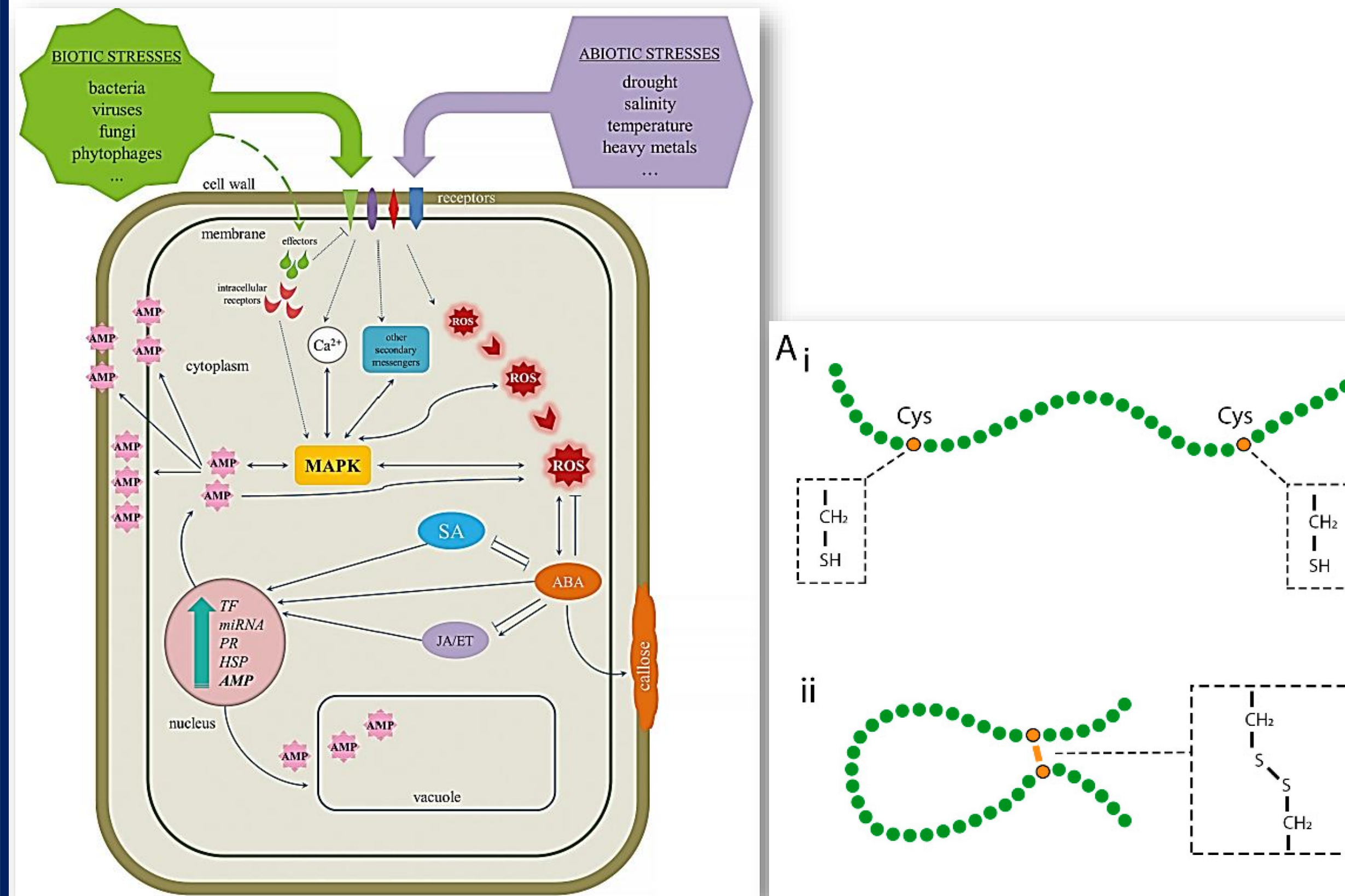


Fig. 1: Symbiotic bacteria (cyan) help fix nitrogen in the root nodules of legumes

The most common group of these effector molecules, mainly for counteracting biotic stress response in plants, is antimicrobial peptides (AMPs). Plant AMPs are small and very diverse peptides containing from 7 to 100 amino acids, and consist of cysteine residues. Hence, they are termed as cysteine-rich peptides. These cysteine-peptides are divided into several main families (thionins, defensins, hevein-like peptides, etc.) that contain conserved cysteine residues.

2

Legumes and nodule-specific cysteine-rich peptides

Legumes are widely known to form a symbiosis with nitrogen-fixing bacteria called rhizobia. This process has evolved multiple times within the legume crops such as beans, peas and soybeans. These rhizobia are usually found in the root nodules of legumes, and help to produce nitrogen compounds that help the plant to grow and compete with other plants. This symbiotic relationship is possible by legume-encoded small peptides known as nodule-specific cysteine-rich (NCR) peptides.

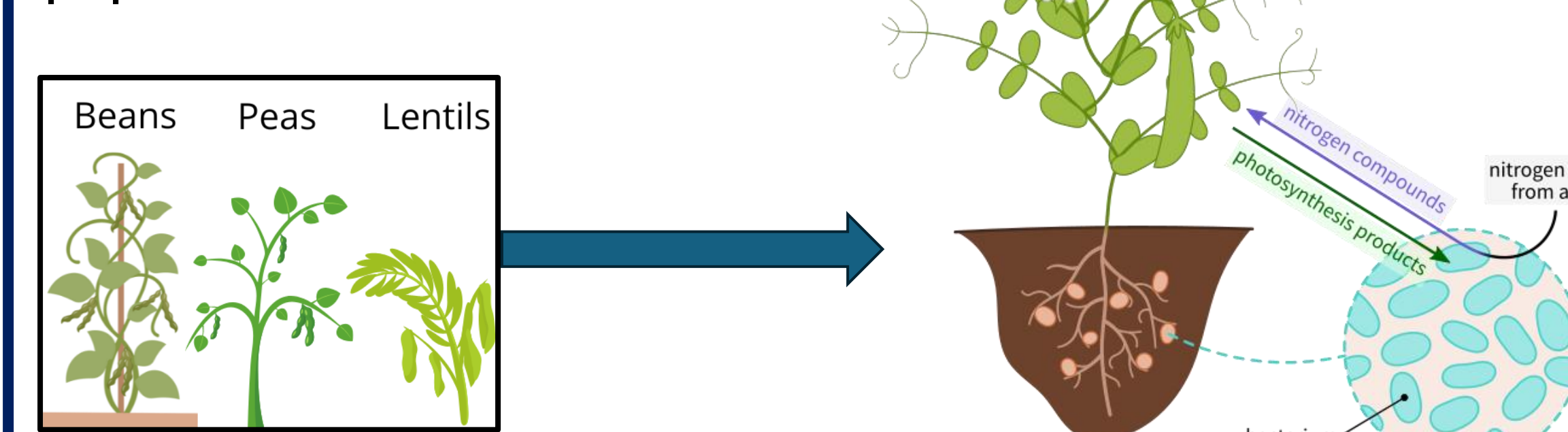


Fig 3: Symbiotic bacteria (cyan) help fix nitrogen in the root nodules of legumes

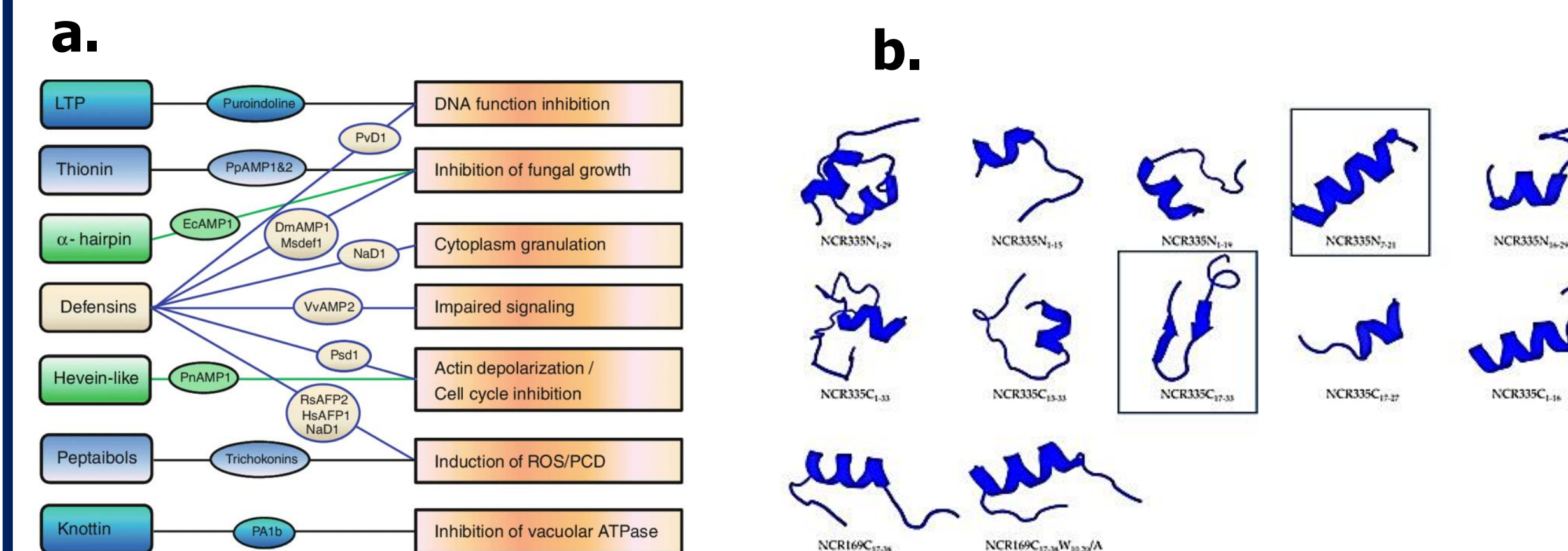


Fig 4: a. Various defensive molecules secreted by plants. B. NCR peptides (b) are unique peptides found in most leguminous plants for symbiosis with rhizobia

NCR peptides are unique peptides that resemble the features of defensins. They are 20 and 50 amino acids long. The peptides have four or six cysteine residues, bringing stability through intramolecular disulfide linkages. While the positioning of these cysteine pairs is highly conserved, the high number and diversity of sequences and the physicochemical properties of NCR peptides offer many potential functions and ways to modulate bacterial metabolism.

3

NCR Function and Mechanism

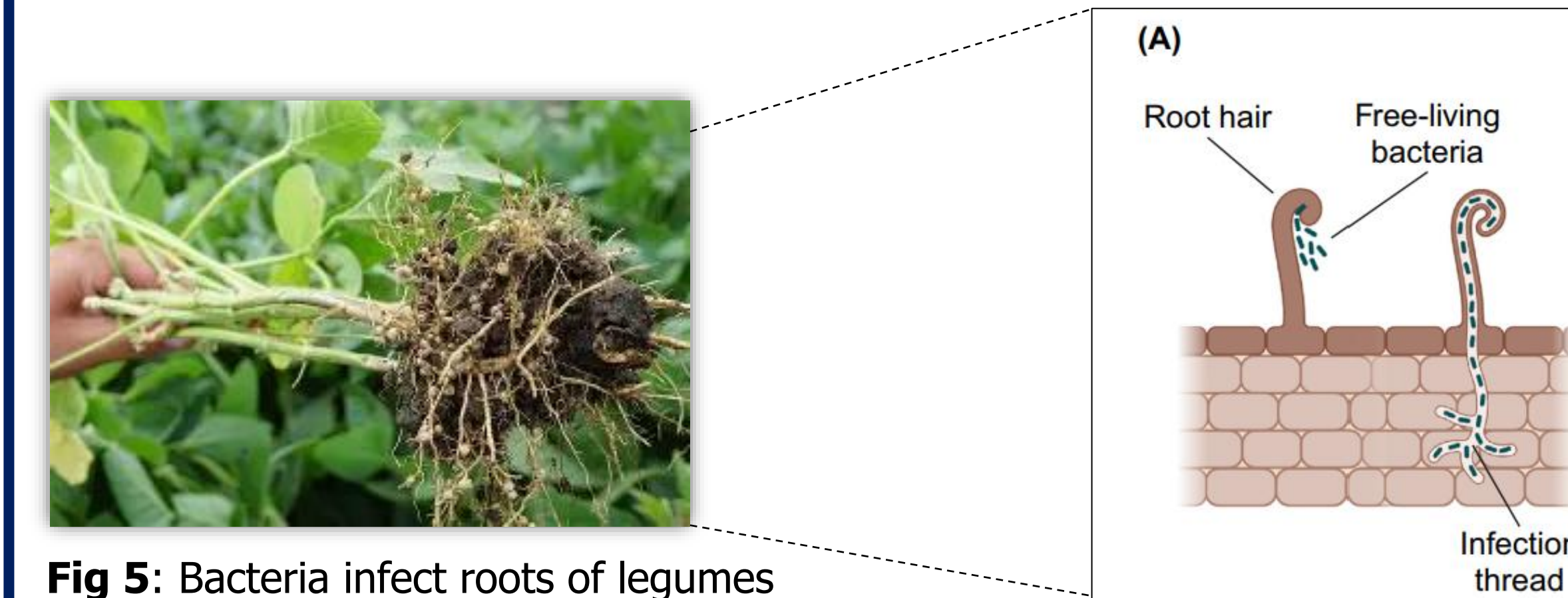


Fig 5: Bacteria infect roots of legumes

Bacteria infect roots of legumes and establish intracellular relationships that will meet the nitrogen requirements of the plant. Consequently, the plant provides the bacteria with energy and carbon sources. Interestingly, the plant also transforms rhizobia into highly efficient nitrogen-fixing machinery, rendering them incapable of surviving outside the host.

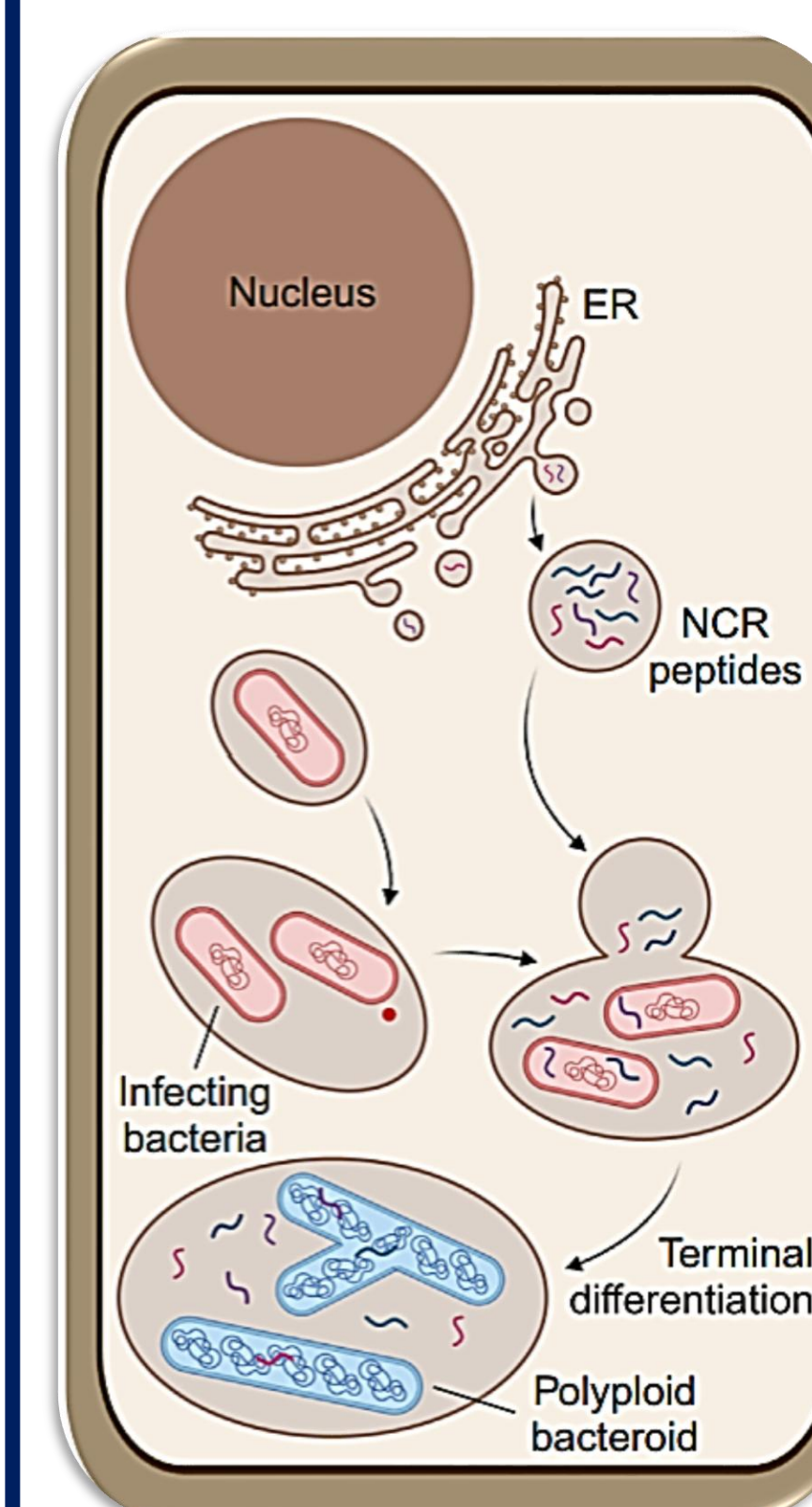


Fig 6: Process of terminal differentiation in legume-rhizobia symbiosis

NCR peptides govern the terminal (ie. irreversible differentiation of nodule bacteria into a symbiotic form called bacteroids). This simply means that the peptides convert the bacteria into a form that enables the bacteria to not only fix nitrogen in the plant but also lose their ability to multiply. Literally, these peptides "enslave" the bacteria.

Interestingly, NCR peptides can also kill bacteria that are not compatible with the plant, thus demonstrating another form of antimicrobial activity.

The ability of NCR peptides to kill a wide range of bacteria apart from rhizobia makes them a viable source for the design of new antibiotics.

4

Current findings and Future Potential

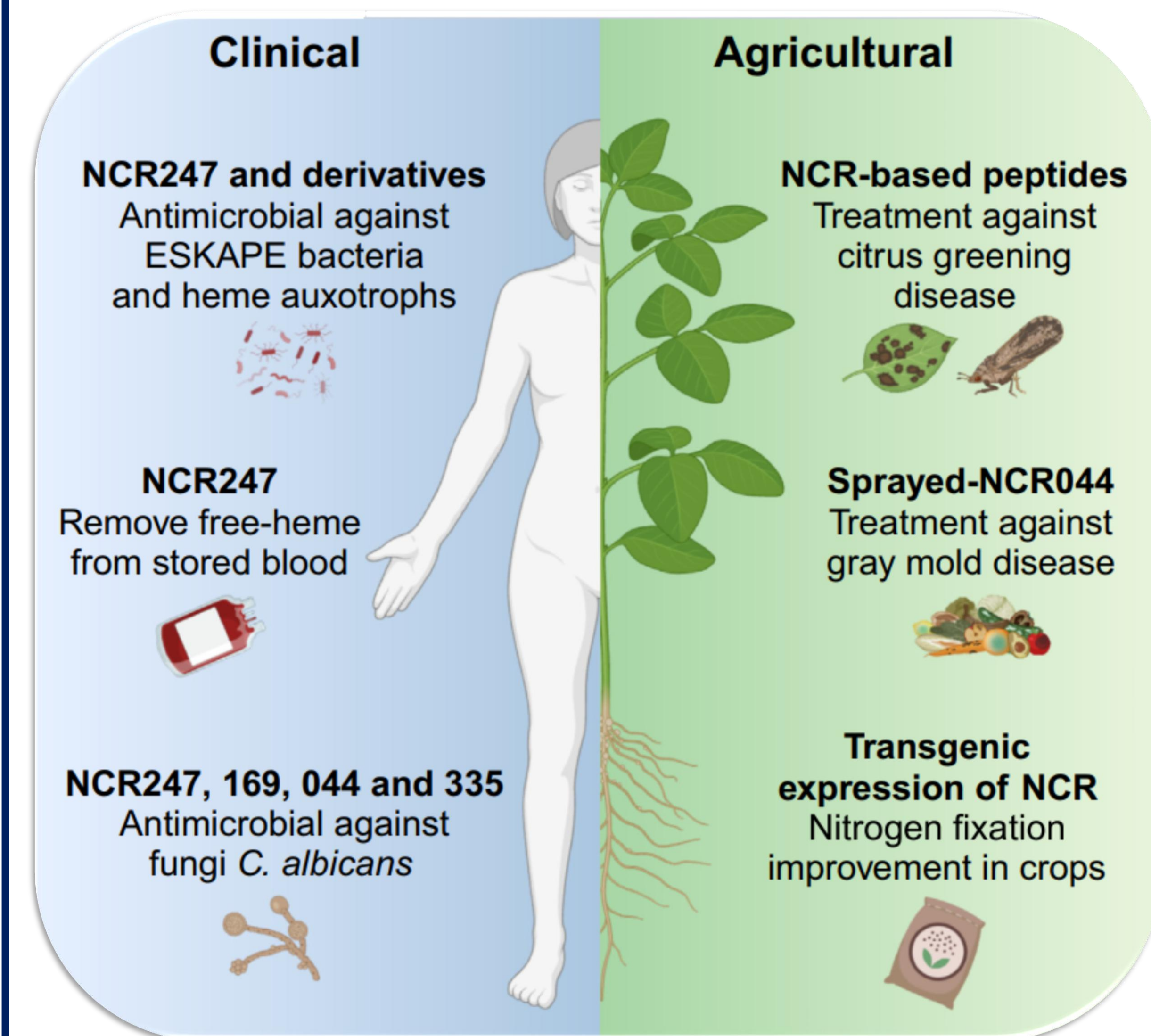


Fig 7: Relevant applications of NCR peptides in clinical and agricultural field

- Cationic NCR peptides from *Medicago truncatula* exhibit broad-spectrum antimicrobial activity against Gram-positive/negative bacteria and various fungi, highlighting their potential as novel antibiotic sources.
- Other NCR peptides significantly reduced gray mold diseases, a major fungal pathogen affecting a broad range of crops.
- Future research directions include identifying specific peptides responsible for symbiotic relationships, investigating peptide-microorganism interactions through computational and experimental approaches, and designing new antimicrobial peptides for pathogen control in the field of medicine and agriculture.