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Influence of Root Exudates on the Rhizospheric Environment

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Abstract:
Root Exudates effect in soil around the root which in plant growth, disease suppression etc

INTRODUCTION

In 1904 the German agronomist and plant physiologist Lorenz Hiltner first coined The term "rhizosphere" to describe the plant-root interface, a word originating in part from the Greek word "rhiza", meaning root (Hiltner, 1904; Hartmann *et al*., 2008). Hiltner described the Rhizosphere as the area around a plant root that is inhabited by a unique population of Microorganisms influenced, he postulated, by the chemicals released from plant roots. In the Years since, the rhizosphere definition has been refined to include three zones which are defined Based on their relative proximity to, and thus influence from, the root The endorhizosphere includes portions of the cortex and endodermis in which microbes and Cations can occupy the "free space" between cells (apoplastic space). The rhizoplane is the Medial zone directly adjacent to the root including the root epidermis and mucilage. The Outermost zone is the ectorhizosphere which extends from the rhizoplane out into the bulk Soil. As might be expected because of the inherent complexity and diversity of plant root Systems, the rhizosphere is not a region of definable size or shape, but instead, consists of a Gradient in chemical, biological and physical properties which change both radially and Longitudinally along the root tip. Root exudate is one of the ways for plant communication to the Neighbouring plant and adjoining of microorganisms present in the rhizosphere of the root. The Chemicals ingredients of the root exudates are specific to a particular plant species and also Depend on the nearby biotic and abiotic environment.

The chemical ingredient exuded by plant Roots include amino acids, sugars, organic acids, vitamins, nucleotides, various other secondary Metabolites and many other high molecular weight substances as primarily mucilage and some Unidentified substances.Through the exudation of a wide variety of compounds, roots may regulate the soil microbial Community in their immediate vicinity, cope with herbivores, encourage beneficial symbioses, Change the chemical and physical properties of the soil and inhibit the growth of competing Plant species. Root exudates mediate various positive and negative interactions like plant-plant and plant-microbe interactions. Plants secrete both high-and low-molecular weight compounds from their roots, and these root exudates function not only as nutrients for soil microbes but as Signal molecules in plant– microbe interactions.

All plants establish symbiotic interactions with rhizobia and arbuscular mycorrhizal fungi to Obtain several nutrients such as nitrogen and phosphate. In these interactions, flavonoids and Strigolactones in root exudates serve as signal molecules to establish the symbiotic interactions.

Root exudates from some plants also function to acidify surrounding soils to acquire phosphate. Unseen part of the plant secretes chemical compounds which acts as communication Signal between the adjacent plant and microbial community present in the rhizosphere of the Root. Root exudates correspond to an important source of nutrients for microorganisms in the Rhizosphere and seem to participate in early colonization inducing chemotactic responses of Rhizospheric bacteria (Bacilio *et al*., 2002). The compounds secreted by plant roots serve important roles as chemical attractants and Repellants in the rhizosphere, the narrow zone of soil immediately surrounding the root system (Bais *et al*., 2001). The chemicals secreted into the soil by roots are broadly referred to as root Exudates. Through the exudation of a wide variety of compounds, roots may regulate the soil Microbial community in their immediate vicinity, cope with herbivores, encourage beneficial Symbioses, change the chemical and physical properties of the soil, and inhibit the growth of Competing plant species.

The ability to secrete a vast array of compounds into the rhizosphere is one of the most Remarkable metabolic features of plant roots, with nearly 5% to 21% of all photosynthetically Fixed carbon being transferred to the rhizosphere through root exudates. Although root Exudation clearly represents a significant carbon cost to the plant, the mechanisms and Regulatory processes controlling root secretion are just now beginning to be examined. Root Exudates have traditionally been grouped into low- and high Mr compounds.

Classification of root exudates

Usually, root exudates have been broadly classified into three categories based on their Molecular masses for research convenience. They are,

A) **LMW (low-molecular-weight) compounds**:- The low molecular weight root exudates Mainly consist of sugar, amino acids, phenol, etc.

B**) HMW (high-molecular-weight) compounds**:- The HMW exudates derive mainly from mucilage and extracellular enzymes, where the mucilage consists of polysaccharides and polyuronic acids.

Mechanism of root exudates release

The release of root exudates is essentially transmembrane transport. Based on the mode Of transportation, the release mechanism of root exudates is divided into two types, passive Transport and active transport (Bertin *et al*., 2003). Passive transport further includes three Pathways. In addition to the three types of passive transport (diffusion, ion channels, and vesicle Transport), root exudates can also travel in an active transport via proteins located in the root Plasmatic. The root exudates released via proteins are mainly primary and secondary Metabolites. Primary metabolites refer to various chemical substances released by the root System to maintain plant growth and development in the face of external stress, while secondary Metabolites do not directly contribute to plant growth and development, but rather indirectly Improve the plants' adaption to adversity by altering their surround environment.

Root exudates from the non-metabolic pathway are not regulated by plant metabolism, mainly including Intercellular permeates, decomposition products, and inclusions of root cells. Transporters are A class of proteins with transmembrane transport functions. These proteins are usually Embedded in biofilms in the form of oligomerization to form unique channel structures.

Transporters can be divided into two categories according to whether they have an ATP-binding domain. One is the ATP-binding cassette (ABC), which has an ATP-binding Domain a hind obtains energy through hydrolysis of ATP in the transport process and the H^+/Na^+Gradient-dependent transporter, which consists of Multidrug and toxic compound extrusion, the major facilitator superfamily (MFS) (Reddy *et al*., 2012) and the aluminum-Activated malate transporter family.

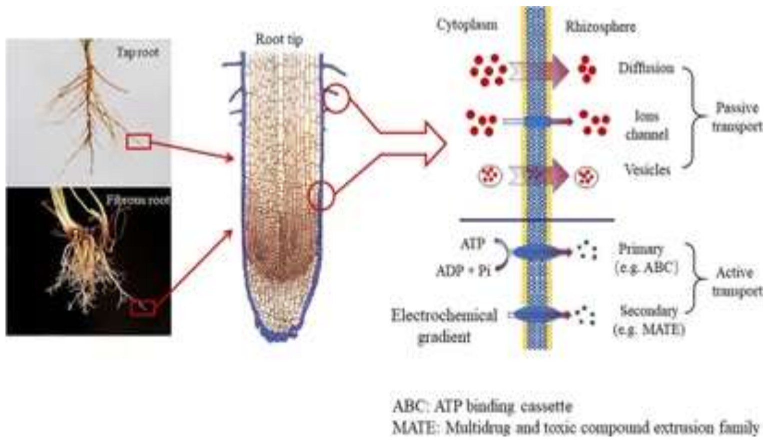

Fig .1: Mechanism of root exudation

Root exudate mediated interactions in rhizosphere

Root -Root interaction

In natural settings, roots are in continual communication with surrounding root systems of neighbouring plant species and quickly recognize and prevent the presence of invading roots Through chemical messengers. Allelopathy is mediated by the release of certain secondary Metabolites by plant roots and plays an important role in the establishment and maintenance of Terrestrial plant communities. It also has important implications for agriculture; the effects may Be beneficial, as in the case of natural weed control, or detrimental, when allelochemicals Produced by weeds affect the growth of crop plant.

A secondary metabolite secreted by the Roots of knapweed (Centaurea maculosa) provides a classic example of root exudates Exhibiting negative root-root communication in the rhizosphere. Interestingly, catechin was shown to account for the allelochemical activity, whereas Catechin was inhibitory to soil-borne bacteria (Bais *et al*., 2001). However, parasitic plants Often use secondary metabolites secreted from roots as chemical messengers to initiate the Development of invasive organs (haustoria) required for heterotrophic growth.

Root- Microbes interactions

Root-microbe interaction is another important process that characterizes the Underground zone. Some compounds identified in root exudates that have been shown to play an important role in root-microbe interactions include flavonoids present in the root exudates of legumes that activate Rhizobium melilotus genes responsible for the nodulation process (Peters *et al*., 1986). Although the studies are not yet conclusive, these compounds may also be Responsible for vesicular-arbuscular mycorrhiza colonization. In contrast, survival of the delicate and physically unprotected root cells under continual Attack by pathogenic microorganisms depends on a continuous “underground chemical Warfare” mediated by secretion of phytoalexins, defence proteins, and other as yet unknown Chemicals. Basil roots were also induced to exude rosmarinic acid (RA) by fungal in situ Challenge with Pythium ultimum, and RA demonstrated potent antimicrobial activity against an Array of soil-borne microorganisms including Pseudomonas aeruginosa.

Root- Insect interactions

The study of plant-insect interactions mediated by chemical signals has largely been Confined to leaves and stems, whereas the study of root-insect communication has remained Largely unexplored due to the complexity of the rhizosphere and a lack of suitable experimental Systems. However, root herbivory by pests such as aphids can cause significant decreases in Yield and quality of important crops including sugar beet (Beta vulgaris), potato (Solanum Tuberosum), and legumes (Hutchison and Campbell, 1994). One attempt to study root-insect Communication was developed by Wu *et al*. (1999) using an in vitro coculture system with Hairy roots and aphids. In this study, it was observed that aphid herbivory reduced vegetative Growth and increased the production of polyacetylenes, which have been reported to be part of The phytoalexin response.

Root exudates- "The hidden part of plant defense"

- Root exudates refers to a suit of substances in the rhizosphere that are secreted by the Roots of living plants and microbially modified products of these substances
- young seedlings typically exuding about 30–40% of their fixed carbon as root exudates
- Root Exudates play a crucial role in plant defense by releasing a variety of chemical Compounds into the soil. These exudates can influence the rhizosphere, the soil region Influenced by root secretions, to enhance nutrient uptake, attract beneficial microbes, And repel or inhibit harmful pathogens

Compositions	**Substances identified**
Organic acid	Acetic, butyric, citric, glutaric, lactic, maleic, malic, malonic, oxalic, propionic, pyruvic, succinic, tartaric, valeric
Amino acid and amide	α-Alanine, β-alanine, arginine, asparagine, aspartic acid, cystine / cysteine, glutamine, glycine, histidine, lysine, methionine, phenylalanine, proline, serine / homoserine
Enzyme	Amylase, invertase, phosphatase, protease, polygalacturonase
Growth factor	*p*-Amino benzoic acid, auxins, biotin, choline, inositol, *n*-methyl nicotinic acid, niacin, pantothenate, pyridoxine, thiamine
Phenolic acid and coumarin	Caffeic acid, cinnamic acid, coumarin, ferulic acid, salycilic acid, syringic acid, vanillic acid
Sugar	Arabinose, fructose, fucose, galactose, glucose, maltose, oligosaccharide, raffinose, rhamnose, ribose, sucrose, xylose
Others	Nucleotide, flavonone, fatty acids, proteins, sterols, lipids, aliphatics, aromatics, carbohydrates

Table 1. Composition of root exudates

INFLUENCE OF ROOT EXUDATES ON RHIZOSPHERIC ENVIRONMENT

Microbial activity and diversity

Plants produce a remarkably diverse array of about 100,000 low-molecular mass Natural products also known as secondary metabolites. These are organic compounds and Inorganic ions that change the chemistry and biology of the rhizosphere and enhance Adaptation to a particular environment. Plant exudates in the rhizosphere provide a rich Source of energy and nutrients for bacteria, resulting in higher bacterial populations in this Area. Rhizosphere microorganisms such as plant growth-promoting rhizobacteria (PGPRs)appear to have the capacity to transform or modify the chemical composition of the Rhizosphere.

Jin *et al.* (2019) evaluated the components of root exudates (citric acid, malic acid, oxalic acid, Fructose, sucrose, glucose, glycine, proline and phenylalanine) on colonization of *Bacillus velezensis* Strain S3-1 in rhizosphere soil. The results indicated that, these compounds of root exudates stimulated. The population of S3-1 adhering to the maize root surface, especially in the presence of malic acid.

Rhizosphere microbes and leguminous plants have beneficial relationships. Their Interaction inhibits or eradicates the invasion of the phytopathogens on the plants. Rhizobia Species, including *Azorhizobium*, *Allorhizobium*, *Bradyrhizobium*, and *Mesorhizobium*, *Sinorhizobium*, are common example inhabiting the rhizosphere of Leguminous plants. The symbiotic association leads to the acquisition of nitrogen in the Soil. Leguminous plants produce nodules and fix nitrogen acquired in the soil during the Symbiotic association with *Bradyrhizobium* strains.

The production of a nodule in legume plants while interacting with rhizosphere microbes Leads to the production of some compounds like flavonoids, betaines, and that stimulates Nodulation by associating with the nod proteins present in the PGPR cell wall. In the root Hair of leguminous plants, the physical effects were revealed when the PGPR (rhizobia) Responded to the production of oligosaccharide nod factors. This results in the production of nodules that eventually promote nitrogen fixation. PGPR, especially rhizobia, contributes t o plant growth and improves the development of seed by producing nod factors like Flavonoids and aldonic acid in the form of root exudates. The exudates signal the PGPR In a mutual association that otherwise promotes the production of the nod gene.

Influence of root exudate on soil structure

Soil conditions are continually modified by the release of organic components from Living roots into the rhizosphere. These organic components have been classified according to Their chemical nature and properties and to their molecular weights. The organic materials released by roots play a major role in the interactions between Roots, microorganisms and soil. The nature and availability of this carbon influence the soil Microflora. Soil microorganisms feed largely on organic substances that originate from root Exudates, of which released sugars represent the most important source for microbial growth. Soil microflora also produce polysaccharides which enhance soil aggregation.

Traore *et al*. (2000) carried out a study to known the effect of root mucilage and modelled root Exudates on soil structure, they concluded that the addition of root exudates increased the stability of Aggregates compared with the control, the proportion of stable aggregates after 30 days of incubation.

<u>Influence of root exudates in disease suppression</u>

Root exudates provide nutrients that encourage the growth of beneficial soil microbes, such as Mycorrhizal fungi and PGPR. By the production of antimicrobial compounds, enzyme Production and signalling molecules.

Yang *et al*., 2016 conducted a study to know the effect of root exudates on mortality of nematodes. Root exudates are collected from the nematode resistance plant .RE are inoculated with the nematode eggs at rate of 0.5, 1 and 2 µM in the petri plates and incubated for hatching, then mortality of nematodes is calculated.

Influence of Root exudates in pollutant detoxification

The rhizospheric bacteria are responsible for the elimination of the contaminants, while the roots are responsible for providing nutrients used by the microorganisms to proliferate. Then strategy was developed to select pollutant-degrading rhizobacteria that live on or are close to the root so that they can use root exudate as their major nutrient source. Root exudates have the potential to increase the degradation of xenobiotics by the growth of Soil microorganisms. Separating the chemical impact of the root exudates from any root surface Phenomena is an important step in isolating a potential mechanism of phytoremediation.

Guo *et al.* (2017) conducted a study to known the effect of artificial root exudates components in facilitating the degradation of pyrene in soil. They revealed that the addition of root exudates (Amino Acid, organic acid and carbohydrate) increased the degradation rate of pyrene in different periods (7, 14 And 21 days) when compared with that of the control.

Allelopathy

Lalit and Jay (2008) investigated the allelopathic effect of sesame root exudates against purple Nut sedge. EW formulation of allelochemicals obtained from root exudates of sesame plants applied on Tubers of purple nut sedge caused the significant delay in and inhibition of germination. Application of 240µg/g of purified allelocompounds of root exudates caused 97 per cent reduction in total number of Newly formed tubers.

Lavanya *et al*. (2007) conducted an experiment to known the allelopathic effect of Chenopodium Weed on the wheat growth. The results revealed that root exudates of Chenopodium reduced the root and shoot length of wheat as compare the control.

Soil structure Modification

Traore *et al.* (2000) carried out a study to known the effect of root mucilage and modelled root Exudates on soil structure, they concluded that the addition of root exudates increased the stability of Aggregates compared with the control, the proportion of stable aggregates after 30 days of incubation

Conclusion

Root exudates plays a vital in shaping the rhizospheric environment through a variety of Mechanisms. They enhance nutrient availability, promote beneficial microbial communities, improve Soil structure, alleviate biotic and abiotic stress. Additionally, root exudates (RE) facilitate plant-plant Interactions, support symbiotic relationships and root architecture. These processes collectively Contribute to plant health, growth and resilience, underscoring the importance of RE in sustainable Agriculture and ecosystem stability.

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