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Plant Root System Architecture and Breeding Strategy for Its Improvement

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Abstract

Roots are crucial for nutrient and water absorption, as well as for storing food in Rooty plants. They can be targeted to improve plant productivity across various growing conditions. Modifying root traits through plant breeding can lead to the development of more stress-tolerant crops and higher yields by improving soil exploration for better water and nutrient absorption. Additionally, roots contribute significantly to carbon sequestration.

Keywords: Root system architecture, crop yield.

Introduction

Roots play vital roles in absorbing water and nutrients, storing resources, anchoring plants, and interacting with various organisms in the soil. The adaptability of root growth to soil conditions offers a chance to study natural diversity for improving plant productivity in agriculture. (Grossman et al. 2012; Kano et al. 2011). The human population is rapidly growing; climate change and unpredictable weather patterns are affecting crop production, increasing the probability of crop failure. To feed an increasing global population, it necessitates agricultural production systems that efficiently capture resources from the soil. Breeding programmes have typically targeted aboveground plant parts (forage, seed, or grain production) to generate food, feed, and fibre. Breeders strive to create enhanced cultivars capable of withstanding various abiotic stress conditions, like drought or flooding. Strategies for "root breeding" require identifying underground root traits that enable plants to efficiently utilise water and nutrients in various environments. Roots perform key physiological functions like storing food, absorbing atmospheric moisture, extracting nutrients from the host, enhancing gaseous exchange, and serving mechanical roles such as floating, providing stronger anchorage, and facilitating climbing via structural modifications.

Need to improve root system

According to a new United Nations assessment released, the world's current population of 7.6 billion is predicted to increase to 8.6 billion in 2030, 9.8 billion in 2050, and 11.2 billion in 2100 (UN Department of Economic and Social Affairs). Food production will need to increase, but the available arable land for agriculture will not grow at the same rate. Enhancing below-ground plant architecture is crucial for supporting future crop production in unstable environments with limited water and nutrients. Various abiotic stresses like drought, submergence, and nutrient imbalances impact plants primarily through their roots.

Figure.1 Different nutrient acquisition strategies

Why root genetic improvement important?

1. **For improving nutrients efficiency:** Unused fertilizer is washing off fields into rivers, polluting coastal waters. Nitrogen use efficiency (NUE) for cereal production is approximately 33% globally. The excess nitrogen from fertilizers leaches into groundwater, causing nitrogen pollution. Low phosphorus levels in soils are a significant constraint for crop production. Only 12–21% of the phosphorus supplied in fertilizers is accessible to plants.
2. **For enhancing tolerance to abiotic stresses:** High salt stress disrupts water potential and ion distribution homeostasis. The exclusion of Na^+ and Cl^- by roots is crucial for plants in saline soils.
3. **For increasing productivity:** Sink size affects the plant yield. Sink size is closely associated with plant yield. A rapid decrease in root activity during the grain filling stage resulted in a low percentage of filled grains.

Efforts to manipulate root system architecture (RSA) in crops

Most progress has been achieved in rice, possibly due to the overexpression of transcription factors *OsNAC5/9* and *OsMYB2*, the receptor kinase *PSTOL1*, the G-protein coding Root Architecture Associated (*OsRAA1*), and the identification of the *DRO1* allele. Two key genes identified for altering root architecture in rice are *DRO1* and *PSTOL1*. Root angle and depth can now be specifically targeted in rice through breeding or transgenic methods using *DRO1* to achieve the desired steep-deep ideotype. A significant QTL for phosphorus deficiency tolerance in rice, *PSTOL1*, encodes a receptor-like kinase that has been mapped and shown to enhance root biomass. Recent advancements in molecular biology and biotechnology have introduced various breeding techniques for practical crop improvement, including DNA marker-assisted selection, genomic selection, and genome editing. These methods are anticipated to be utilized for breeding root traits that are challenging to select based on phenotype in the field.

In maize, the auxin-responsive LOB domain transcription factor, Rootless concerning the crown and seminal root (RTCS), along with its downstream target, Auxin Responsive Factor (*ARF34*), regulates nodal root formation in monocots. The genes short lateral roots 1 and 2 (*slr1*, *slr2*) and lateral root 1 *(lr1*) govern lateral root development in maize. Various root structure QTLs in maize influence architecture and yield stability across different genetic backgrounds and water regimes. In rice, root structure is influenced by genes like the auxin-regulated Adventitious and Crown Rootless *ARL1* and *CRL1*, a conserved LOB domain transcription factor in monocots and dicots. In times of low rainfall, ongoing water evaporation from the soil surface leads to drought conditions. A deeper root system architecture (RSA) may offer advantages compared to the norm under normal conditions. In rice, a deeper root phenotype is associated with a functional allele at *DEEPER ROOTING 1* (*DRO1*), a locus influencing root growth angle, mitigating the effects of drought stress. Research shows that a functional *DRO1* allele boosts grain yield, while a shallow root phenotype due to a non-functional *DRO1* allele is vulnerable to drought stress.

When water covers the soil surface, field crops may suffer stress disorders like root rot due to a lack of oxygen. Developing soil-surface roots (SOR) could help plants access oxygen even when flooded. A QTL linked to SOR formation, known as *SOIL SURFACE ROOTING* (*qSOR1*), has been identified in Bulu ecotype rice. In a paddy field under reduced stress, rice plants with SOR showed higher grain yields than those without. Nitrogen in fields easily moves to the subsoil with water, so RSAs with steeper, longer, thicker roots are best for N accumulation. An ideal RSA for maize, steep, cheap, and deep, could enhance N and water uptake from the subsoil.

Problems and prospects

Although the root is an important plant part that significantly influences yield and productivity, little research has focused on its genetic basis compared to above-ground parts. Root phenotyping is challenging, with limited methods for in situ phenotyping to understand temporal and spatial root characteristics. Current soil culture methods mimic the soil environment but lack the resolution needed for drawing robust conclusions.

Conclusion

Root system architecture (RSA) is dynamic and influenced by external factors such as soil moisture, temperature, nutrients, and pH, as well as the surrounding microbial communities. These factors play a crucial role in how plants perceive and react to their environment. Varied root traits allow plants to adjust, adapt, and prosper in diverse surroundings.

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