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Breeding strategy and the architecture of the plant root system for its improvement

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Abstract:-

Roots are crucial for absorbing water and nutrients from the soil. The structure of the root system, known as root system architecture (RSA), dictates the area of soil that roots can explore for these resources. By altering root characteristics through plant breeding, it is possible to create crops that are more resilient to stress and produce higher yields by enhancing their ability to access water and nutrients. Moreover, roots play a significant role in sequestering carbon, contributing to environmental sustainability.

Keywords: Root system architecture, salt- tolerance crops and crop yield.

Introduction:

Roots are essential for water and nutrient absorption, resource storage, plant anchorage, and interactions with soil organisms. Their growth adaptation to soil conditions presents an opportunity to explore natural diversity for enhancing agricultural productivity. With a rapidly growing global population and the impacts of climate change causing unpredictable weather and crop failures, there is a pressing need for agricultural systems that efficiently utilize soil resources. Traditionally, breeding programs have focused on improving aboveground plant parts for food, feed, and fiber production. However, to develop cultivars that can endure abiotic stresses such as drought and flooding, it is crucial to identify and target key underground root traits. Roots fulfill important physiological roles, including food storage, moisture absorption, nutrient extraction, and gaseous exchange, as well as mechanical roles like providing stronger anchorage, floating, and aiding climbing through structural modifications.

Need to improve root system

According to a recent United Nations assessment, the global population, currently at

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7.6 billion, is expected to rise to 8.6 billion by 2030, 9.8 billion by 2050, and 11.2 billion by 2100 (UN Department of Economic and Social Affairs). This population growth will demand a significant increase in food production, despite the fact that the expansion of arable land will not keep pace. Enhancing the below-ground architecture of plants is essential to sustain future crop yields in environments characterized by limited water and nutrients. Various abiotic stresses, such as drought, submergence, and nutrient imbalances, predominantly affect plants through their root systems.

Why root genetic improvement important?

1. To enhance nutrient efficiency, it's important to address the issue of unused fertilizer runoff, which contaminates rivers and coastal waters. Globally, nitrogen use efficiency (NUE) for cereal production is around 33%, meaning a significant portion of applied nitrogen is lost, leaching into groundwater and causing nitrogen pollution. Additionally, low phosphorus levels in soils pose a major limitation for crop production, with only 12–21% of the phosphorus from fertilizers being available 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

Compared to components of the plant that are above ground, the genetic basis of the root has received less attention, despite the fact that it is an essential component that greatly affects productivity and yield. With few techniques for in situ phenotyping to comprehend temporal and spatial root features, root phenotyping is difficult. Although current methods for soil culture replicate the soil environment, they are not as precise as needed to make strong conclusions.

Conclusion

The microbial populations in the surrounding soil, as well as external elements like temperature, pH, nutrients, and moisture levels, all have an impact on the dynamic root system architecture (RSA). These elements are essential to how plants view and respond to their surroundings. Different root characteristics enable plants to thrive in a variety of environments.

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