The Battle of Ascorbic Acid Rich vs. Poor Chickpea Genotypes Under Drought

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Abstract

This study underscores the pivotal role of ascorbic acid (AsA) in enhancing drought resilience in chickpea (*Cicer arietinum* L.) genotypes. Results demonstrated that AsA-rich genotypes significantly outperformed their AsA-poor counterparts under water-stressed conditions. These genotypes exhibited higher activity levels of stress-responsive enzymes such as ascorbate peroxidase (APX) and glutathione reductase (GR), accumulated greater proline concentrations, and nearly doubled their AsA content compared to their initial levels. In contrast, AsA-poor genotypes showed lower enzymatic activity, insufficient AsA accumulation, and suffered more substantial yield losses under drought stress. This evidence highlights the strategic importance of incorporating AsA-rich traits into breeding programs to develop chickpea varieties with greater yield stability and drought tolerance. By prioritizing AsA-enriched genotypes, sustainable agricultural practices can address the pressing challenges of food security in arid and semi-arid regions, offering a promising pathway to mitigate the impacts of climate change.

Introduction

Drought represents a severe and persistent challenge to global agriculture, posing substantial threats to the production of staple crops. Among these, chickpea holds immense importance as a primary source of nutrition and livelihood for millions, particularly in arid and semi-arid regions. As climate change exacerbates water scarcity, chickpea cultivation faces significant obstacles, necessitating innovative approaches to enhance its drought tolerance. AsA, commonly known as vitamin C, has emerged as a critical player in plant resilience under abiotic stresses such as drought. Acting as a potent antioxidant, AsA mitigates the oxidative damage caused by reactive oxygen species (ROS), which accumulate during water stress. Additionally, AsA enhances the activity of stress-responsive enzymes and contributes to maintaining cellular integrity and osmotic balance under adverse conditions. This study explores the comparative performance of AsA-rich and AsA-poor chickpea genotypes under drought conditions, highlighting the mechanisms through which AsA confers drought resilience.

Stress Fighting Superheroes: AsA-Rich Genotypes

Under both well-watered and drought conditions, AsA-rich chickpea genotypes consistently demonstrated superior performance across key physiological and biochemical parameters compared to their AsA-poor counterparts.

Higher Stress-Enzyme Activity

AsA-rich genotypes exhibited significantly higher activity levels of stress-responsive enzymes, such as APX and GR, both of which play critical roles in detoxifying ROS during drought stress.

- **APX Activity:** AsA-rich genotypes recorded APX activity levels up to 450 nmoles of ascorbate oxidized per minute under drought conditions, a substantial improvement over the ~300 nmoles observed in AsA-poor genotypes. This heightened activity underscores the superior oxidative stress management in AsA-rich genotypes.
- **GR Activity:** Similar trends were observed for GR activity, with AsA-rich genotypes demonstrating nearly double the enzymatic activity of their counterparts. GR helps regenerate reduced glutathione, an essential molecule for redox homeostasis and stress mitigation.
- **Enhanced AsA Content**: Under water-stressed conditions, AsA-rich genotypes significantly increased their internal AsA levels, nearly doubling the content recorded under well-watered conditions. This accumulation was crucial for sustaining ROS scavenging and maintaining cellular functions. In contrast, AsA-poor genotypes failed to achieve comparable increases, limiting their ability to combat oxidative damage.
- **Proline Accumulation**: Proline, a well-known Osmo protectant, was markedly higher in AsA-rich genotypes under drought conditions. Proline accumulation in these genotypes increased by approximately 90% compared to their AsA-poor counterparts. This enhanced proline content supports osmotic balance, stabilizes proteins and

membranes, and serves as an energy source during stress recovery.

The Struggle of AsA-Poor Genotypes

In stark contrast, AsA-poor chickpea genotypes displayed limited capacity to withstand drought, characterized by:

- **Lower Enzyme Activity:** The reduced activity of APX and GR in AsA-poor genotypes hindered their ability to detoxify ROS, leading to greater cellular damage under water stress.
- **Inadequate AsA Levels:** These genotypes struggled to enhance their AsA content during drought, limiting their antioxidant defenses and stress adaptation mechanisms.
- **Greater Yield Losses:** AsA-poor genotypes experienced sharp declines in seed production under drought conditions, reflecting their inability to maintain metabolic functions essential for reproductive success.

The diminished stress tolerance of AsA-poor genotypes highlights the critical need to prioritize AsA enrichment in breeding programs to develop chickpea varieties with improved drought resilience.

The Takeaway for Chickpea Breeding

The findings of this study offer valuable insights into breeding strategies for chickpea under drought conditions.

- **Enhanced Resilience:** AsA-rich genotypes not only survive but thrive under water-stressed environments by leveraging their superior stress-responsive mechanisms.
- **Yield Stability:** By maintaining higher enzyme activity, AsA levels, and proline accumulation, these genotypes exhibit greater yield stability in arid and semi-arid regions, where drought is a recurring challenge.
- **Breeding Focus:** Incorporating AsA-rich traits into chickpea breeding programs is a critical step toward developing drought-tolerant varieties. This approach not only ensures higher productivity but also contributes to sustainable agricultural practices by reducing the reliance on external inputs such as irrigation.

By harnessing the potential of AsA, breeding programs can unlock new pathways to bolster chickpea cultivation in water-scarce environments, offering hope to farmers grappling with the harsh realities of climate change.

Conclusion

- This study highlights the critical role of AsA in enhancing drought resilience in chickpea genotypes.
- AsA-rich genotypes consistently outperformed their AsA-poor counterparts by exhibiting higher activity levels of stress-responsive enzymes such as APX and GR, accumulating more proline, and nearly doubling their AsA content under water-stressed conditions.
- In contrast, AsA-poor genotypes struggled to cope with drought, showing lower enzyme activity, inadequate AsA levels, and significantly greater yield losses.
- These findings emphasize the importance of prioritizing AsA-rich traits in breeding programs to develop drought-tolerant chickpea varieties.
- By focusing on AsA-enriched genotypes, breeding strategies can ensure higher yield stability and resilience in arid and semi-arid regions, offering a sustainable solution to the challenges posed by climate change.

Prospective Developments

The integration of AsA-related traits into breeding pipelines provides a promising strategy to address food security concerns and mitigate the adverse effects of climate change on agriculture. With continued research and investment in AsA-focused breeding programs, chickpea can serve as a model crop for resilience, enabling sustainable production even under the harshest environmental conditions.

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