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Editorial

Research on Pomegranate Germplasm, Breeding, Genetics and Multiomics

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1. Introduction

Pomegranate (*Punica granatum* L.), a fruit-bearing shrub with a rich cultural history [1,2], has long been appreciated for its unique flavor, nutritional value, and ornamental beauty. Native to the region stretching from Iran to northern India, pomegranate has been cultivated for thousands of years and is now grown globally in various climates [3,4]. Its fruits are valued for their antioxidant-rich arils [2,4,5], while ornamental varieties are sought after for their vibrant flowers and esthetic appeal. The importance of pomegranate in both culinary and medicinal traditions, coupled with its increasing demand in the global market, has spurred significant research into improving its yield, quality, and resilience [6–8].

In recent years, the advent of advanced genomics, transcriptomics, and phenotyping tools has allowed researchers to delve deeper into the genetic architecture of pomegranate, leading to new insights into its complex biology. These breakthroughs have significantly enhanced our ability to explore traits of agronomic importance, such as fruit quality [4,9–11], disease resistance [12], and stress tolerance [13,14]. Despite this progress, several gaps in our knowledge have persisted. Key questions remain regarding the genetic regulation of traits like fruit morphology, color [15,16], and texture, as well as the molecular mechanisms that underpin disease resistance and environmental adaptability [12].

Traditional breeding approaches, while effective, are often slow and constrained by the complex genetics of pomegranate, particularly when dealing with polygenic traits [3]. Moreover, the pomegranate germplasm is highly diverse, with many landraces and wild relatives showing wide variability in important traits [17]. As a result, molecular breeding and biotechnological tools are increasingly seen as indispensable in accelerating pomegranate improvement efforts [18,19].

However, until recently, comprehensive genomic resources for pomegranate have been limited. A complete reference genome has only been available for a short time, and the functional characterization of key genes and regulatory elements remains in its early stages. Moreover, the integration of multiomics approaches—combining genomics, transcriptomics, proteomics, and metabolomics—has been underutilized in pomegranate research [20]. These limitations have hindered our ability to fully exploit the genetic diversity of pomegranate and make precise, targeted improvements in breeding programs.

The goal of this Special Issue, "Research on Pomegranate Germplasm, Breeding, Genetics, and Multiomics", is to address these gaps by compiling cutting-edge research that advances our understanding of pomegranate at the genetic, molecular, and phenotypic levels. This collection of studies highlights the diversity and depth of current research, ranging from gene family analyses and molecular marker identification to postharvest treatment studies and disease resistance. By presenting this research, the Special Issue aims to offer a more comprehensive view of the genetic underpinnings of important traits and

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provide new tools and resources for breeders, researchers, and the broader horticultural community.

Moreover, the recent focus on integrating multiomics approaches in plant research offers exciting new avenues for exploration. By connecting the dots between genomic data and observable traits, researchers can better understand how genetic variation influences phenotypic diversity and develop strategies to improve pomegranate cultivars in a more targeted manner. The growing availability of genomic resources, including genome sequences and gene expression data, opens the door to more sophisticated breeding techniques, such as marker-assisted selection (MAS), genomic selection (GS), and even CRISPR-based genome editing.

This Special Issue also underscores the importance of interdisciplinary research, combining classical breeding with modern genetic technologies to address practical challenges such as improving disease resistance, extending postharvest shelf life, and enhancing fruit quality for both fresh consumption and industrial processing. As the pomegranate industry continues to grow, driven by increasing consumer demand for nutritious and functional foods, there is an urgent need to develop new cultivars that are resilient, high-yielding, and tailored to specific market needs.

By fostering a deeper understanding of the genetics and molecular biology of pomegranate, this Special Issue not only fills crucial gaps in our current knowledge but also sets the stage for future research aimed at sustainable and efficient pomegranate breeding and cultivation practices. It is hoped that this collection of articles will inspire further investigation and collaboration within the scientific community, ultimately leading to the development of new technologies and innovations that will benefit pomegranate growers and consumers alike.

2. Overview of Published Articles

This Special Issue includes ten research articles (List of Contributions). The ten articles offer comprehensive insights into the pomegranate's genetic and phenotypic diversity, genomic resources, and molecular mechanisms underlying critical traits. The research presented spans from fundamental genomic studies to applied horticultural practices, reflecting the ongoing progress in pomegranate breeding, multiomics, and postharvest management. A summary of the contributions is provided below.

2.1. Genetic Variation and Phenotypic Traits

A study on ornamental pomegranate investigates the genetic basis of floral morphology, linking genomic variation to petal traits, providing critical markers for breeding efforts aimed at ornamental purposes (Contribution 1). Another article (Contribution 2) delves into the role of anthocyanidin synthase (ANS) genes in anthocyanin biosynthesis, which determines fruit color, a major determinant of marketability. The comprehensive genomic identification and characterization of the ANS gene family contribute to understanding how color can be genetically manipulated to enhance consumer appeal. Additionally, researchers explore the expansin gene family, which influences fruit growth and texture, another vital quality trait for commercial production (Contribution 3). Research continues with a detailed analysis of the UDP-glycosyltransferase (UGT) gene family, providing insights into its role in synthesizing key flavonoids and other secondary metabolites (Contribution 4). This work not only uncovers the genetic underpinnings of fruit flavor and nutritional composition but also highlights potential targets for improving these characteristics through molecular breeding. The in-depth exploration of transcription factors like R2R3-MYB, involved in regulating anthocyanin and flavonoid biosynthesis, further enriches our understanding of the regulatory networks controlling secondary metabolism (Contribution 5).

2.2. Postharvest Physiology

One of the studies examines the effects of 1-methylcyclopropene (1-MCP) on maintaining the quality of pomegranate fruits during low-temperature storage (Contribution 7). This research provides valuable insights into delaying senescence and preserving fruit quality, which is crucial for extending shelf life and reducing postharvest losses—a key concern for both growers and retailers.

2.3. Disease Resistance and Environmental Stress

A study focused on anthracnose fruit rot caused by *Colletotrichum gloeosporioides*, a serious issue in the southeastern United States, identifies cultivars exhibiting strong resistance to the pathogen (Contribution 8). This finding is particularly relevant for developing disease-resistant cultivars for commercial cultivation in regions prone to this and similar diseases. Studies investigating lignin biosynthesis and the associated laccase gene family shed light on structural aspects of the pomegranate, particularly regarding tree integrity and stress tolerance (Contribution 6). These findings have practical implications for developing cultivars better equipped to withstand environmental challenges, such as drought and pathogen attacks.

2.4. Reproductive Biology

In addition to gene families and stress resistance, this Special Issue presents research on reproductive biology through the analysis of microRNAs (miRNAs) associated with pistil development (Contribution 9). By identifying miRNAs that regulate key developmental processes, this research offers insights that could enhance fruit set and yield through targeted breeding approaches.

2.5. Phenotypic Diversity

A study on the phenotypic diversity of pomegranate cultivars highlights the discriminating power of morphological and chemical characteristics (Contribution 10). This phenotypic diversity is invaluable for both germplasm conservation and breeding, offering a solid foundation for developing superior cultivars tailored to specific market or environmental needs.

In conclusion, this Special Issue bridges significant knowledge gaps by combining molecular, genomic, and phenotypic approaches, paving the way for future research that could further enhance pomegranate breeding and cultivation strategies. The integration of multiomics approaches promises to continue advancing the field, ultimately contributing to the development of more resilient, high-quality pomegranate cultivars.

3. Summary and Future Outlook

The contributions in this Special Issue underscore the remarkable progress that has been made in the field of pomegranate genetics and breeding. However, they also highlight the remaining challenges that need to be addressed to fully harness the genetic potential of this species. Future research should prioritize the following areas:

3.1. Integrating Multiomics Approaches

While considerable strides have been made in genomic and transcriptomic research, integrating these data with proteomic, metabolomic, and phenomic studies will provide a more holistic understanding of how genetic variation translates into phenotypic traits.

3.2. Functional Genomics and Gene Editing

The identification of key genes involved in traits like fruit quality, disease resistance, and stress tolerance is only the first step. Future efforts should focus on functional validation of these genes, utilizing CRISPR/Cas9 and other gene-editing technologies to accelerate the development of improved cultivars.

3.3. Climate Resilience

As global climates continue to change, developing pomegranate varieties that can withstand abiotic stresses such as drought will be critical. The role of transcription factors, such as the MYB family, in abiotic stress responses presents a promising avenue for future research.

3.4. Postharvest Biology

While this Special Issue has advanced our understanding of postharvest treatments, more research is needed to optimize storage conditions and explore natural alternatives to chemical treatments, ensuring the sustainability of the pomegranate industry.

3.5. Breeding Meeting Consumer Preferences and Marketability

As the pomegranate market grows, consumer-driven traits such as fruit flavor, texture, and nutritional content will increasingly influence breeding priorities. Understanding the genetic basis for these traits and translating that knowledge into actionable breeding strategies should be a key focus.

In conclusion, this Special Issue has laid a solid foundation for the future of pomegranate research, presenting key discoveries and offering a roadmap for addressing the remaining challenges. We hope that the findings presented in this edition will inspire further investigation and innovation, ultimately contributing to the sustainable cultivation and global appreciation of this remarkable fruit species.

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