



Short Review Paper

WUSCHEL: The master transcription factor in plant developmental biology

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Abstract

Homeodomain transcription factors are proteins that bind to DNA by conserved HTH motif regions that controls and regulate expression of many target genes. WUSCHEL (WUS) and WUS-related home box (WOX) are the transcription factor controls shoot meristem activity through various signaling pathways. Another expression gene named CLV3 (CLAVATA) interacts with those homeo domain factors controls the meristems inside a plant. Current research has shown that there is a connection between WUS in the plant signaling pathways during genetic transformation, transition between vegetative structures to embryo formation, other aspect of plant development. In this review I give a detailed study of expression and activity of WUS and WOX gene.

Keywords: Morphogenesis, Embryogenesis, Plant development, Shoot meristem, Transcription factor, WUSCHEL, WUS-related homeobox.

Introduction

Transcription factors play critical roles in regulating gene expression, ultimately controlling plant growth, development, and response to environmental stimuli. Among these, WUSCHEL (WUS), a homeobox-containing transcription factor, is often regarded as a "master regulator" of stem cell maintenance in plants¹. First identified in *Arabidopsis thaliana*, WUS has since become central to understanding how plants regulate meristem activity, the specialized tissue that drives growth at the tips of roots and shoots. The pivotal function of WUS in maintaining stem cells and its interaction with other signalling pathways make it a key target of study in developmental biology. This review will focus on the molecular mechanisms of WUS function, its role in stem cell maintenance, and its integration with hormonal and environmental signals, highlighting recent advances in research. The growth, development and differentiation of tissues, organ of plants is called plant morphogenesis. It takes place in both *in vitro* and *in vivo* condition by the play of several phytohormones¹. Now a day's various transcription factors (TFs) and their participation in various signalling pathways become hot spot in functional genomics and transcriptomics.

Recent research reveals that the signalling cascade of expression of TF genes is necessary for proper development and differentiation. WUSCHEL (WUS) gene expressed as the homeodomain transcription factor, originally identified as a master regulator required for shoot and floral meristem integrity² in *Arabidopsis*. Ectopic overexpression of WUS gene regulates cell fate during cell dedifferentiation including size of

shoot meristem, somatic embryo, adventitious shoot and lateral leaf formation, by maintaining the pluripotent stem cells³.

The Role of Meristems and Stem Cells in Plant Development

In higher plants, meristems are the centre of undifferentiated cells that contribute to postembryonic organ formation. Shoot apical meristems (SAM) and root apical meristems (RAM) are responsible for the continuous formation of new tissues during growth. The regulation of meristem activity is crucial for balancing the maintenance of a stem cell pool and the differentiation of cells into various tissues.

At the core of SAM is a population of pluripotent stem cells maintained by a feedback loop between WUSCHEL and the CLAVATA (CLV) signalling pathway. WUS acts by ensuring the expression of stem cell-promoting genes while preventing differentiation, allowing plants to continuously generate new organs such as leaves, stems, and flowers throughout their life cycle.

Molecular Mechanisms of WUSCHEL Function

WUSCHEL (WUS) is a pivotal member of the WUSCHEL-RELATED HOMEBOX (WOX) family of transcription factors. This family is distinguished by a conserved homeo domain, a structural motif that is essential for the binding of these proteins to specific DNA sequences, thereby regulating gene expression. WUSCHEL is specifically expressed in a limited group of cells located within the organizing center (OC) of the shoot apical meristem (SAM). This spatial restriction is crucial, as WUS acts as a central regulator of stem cell identity

in this region. By maintaining the undifferentiated state of stem cells, WUS ensures proper growth and development in plant meristems.

Its regulatory influence is fundamental to the orchestration of various developmental processes, including the formation of new organs and the maintenance of meristematic activity. Overall, the role of WUS in the OC of the SAM highlights its importance in plant development, acting as a key player in the complex signal lingnet works that govern stem cell behavior and contribute to the overall architecture of the plant⁴.

The WUS-CLV Feedback Loop: One of the best-characterized functions of WUS is its involvement in the WUS-CLAVATA feedback loop. WUS promotes stem cell identity in the SAM by activating genes that maintain stem cell activity, while the CLV signalling pathway restricts the size of the stem cell population. The CLAVATA genes (CLV1, CLV2, and CLV3) negatively regulate WUS expression by inhibiting WUSCHEL's transcription through a receptor-ligand interaction mechanism. CLV3, expressed in the stem cells, encodes a small peptide that binds to the CLV1-CLV2 receptor complex, leading to the down regulation of WUS in the organizing center⁵. This feedback loop ensures the precise control of stem cell population size.

Direct Targets of WUSCHEL: Recent studies have begun to uncover direct targets of WUSCHEL that contribute to its role in stem cell maintenance. WUS has been shown to repress differentiation-promoting genes and to activate genes involved in cytokinin signalling, a hormone that plays a critical role in promoting cell division in the meristem. Notably, WUS directly binds to the promoters of cytokinin-responsive genes, enhancing cytokinin biosynthesis and sensitivity, thereby promoting stem cell fate. WUS also interacts with chromatin remodeling complexes, indicating that it may regulate the epigenetic state of stem cell-specific genes. Through these multiple layers of regulation, WUS ensures the long-term maintenance of stem cell identity in the SAM⁶.

Integration with Hormonal and Environmental Signals

WUSCHEL not only orchestrates stem cell maintenance through the WUS-CLV feedback loop but also integrates hormonal and environmental cues to modulate meristem activity. Cytokinins are key hormonal signals that promote meristematic activity⁷, and WUS is a critical mediator of cytokinin signalling within the SAM. WUS upregulates cytokinin biosynthesis and response pathways, amplifying the hormone's effect on stem cell maintenance.

On the other hand, auxins, another plant hormone, have an antagonistic relationship with WUS. Auxin is known to promote cell differentiation and organogenesis, while WUS represses auxin signalling in the central zone of the meristem to maintain stem cells in an undifferentiated state. The balance between cytokinin and auxin signalling is crucial for proper

meristem function, and WUS plays a pivotal role in maintaining this balance⁸. Environmental factors, such as light, temperature, and nutrient availability, also influence WUS activity, although the exact mechanisms are not fully understood. For example, photoperiod and light quality can impact meristem activity by modulating the expression of WUS and related genes, linking environmental cues with developmental decisions in the plant.

WUSCHEL in Other Plant Species

While most studies have focused on *Arabidopsis thaliana*, WUSCHEL orthologs have been identified in a range of plant species, including rice, maize, and tomato. In these species, WUS performs similar roles in regulating stem cell activity and meristem function, though the specifics of its regulatory network may vary⁹.

For instance, in rice (*Oryza sativa*), a WUS-related gene called *TAB1* has been implicated in inflorescence meristem maintenance, while in tomato (*Solanum lycopersicum*), WUS is involved in regulating floral meristem activity. These findings suggest that the fundamental role of WUS in stem cell regulation is conserved across plant species, though the details of its interactions with other signalling pathways may be species-specific.

Conclusion

WUSCHEL stands out as a master regulator of stem cell maintenance and meristem function in plants. Its ability to coordinate complex gene regulatory networks, integrate hormonal signals, and respond to environmental cues underscores its importance in plant development. Future research will likely focus on unravelling the precise mechanisms of WUS regulation and identifying additional components of its signalling network. Understanding WUS function not only provides insights into the fundamental biology of plant development but also has potential applications in agriculture, where manipulating meristem activity could improve crop yield and resilience.

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