AGRI MAGAZINE
(International E-Magazine for Agricultural Articles)
Volume: 03, Issue: 08 (August, 2026)
Available online at http://www.agrimagazine.in


# Pollen–Pistil Interaction: The Molecular Conversation That Leads to Seed Formation

*S. Pozhilarasi
Research Scholar, Tamil Nadu Agricultural University, Coimbatore, India
*Corresponding Author's email: pozhilarasi7@gmail.com

Pollen–pistil interaction is a highly coordinated molecular process that plays a central role in successful fertilization and seed formation in flowering plants. Following pollination, compatible pollen is recognized and hydrated at the stigma, germinates and produces a pollen tube that grows through the pistil towards the ovule. This journey is regulated by complex interactions involving receptors, signaling molecules, proteins, hormones, calcium ions and reactive oxygen species. During pollen tube growth, dynamic remodeling of the cell wall is essential for maintaining a balance between flexibility and mechanical strength. Pectin, callose, pectin methylesterase (PME) and pectin methylesterase inhibitor (PMEI) are important components of this process. PME regulates pectin de-esterification, while PMEI controls PME activity to maintain appropriate cell-wall properties. In addition, exocytosis and endocytosis continuously deliver, recycle and redistribute cell-wall materials and membrane components at the growing pollen tube tip. Together, these molecular mechanisms enable precise pollen tube growth, guidance and successful delivery of male gametes to the ovule. Understanding this hidden molecular conversation provides valuable insights into plant reproductive biology and has important applications in hybrid breeding, reproductive manipulation and improved seed production. This article highlights the fascinating molecular events underlying pollen–pistil communication and the coordinated mechanisms that transform a single pollen grain into a successful pathway towards seed formation.

**Keywords:** Pollen–pistil interaction; pollen tube growth; pectin; PME; PMEI; callose; fertilization; seed formation; hybrid breeding.

## Introduction

Reproduction is one of the most fascinating processes in nature. In flowering plants, the journey from pollination to seed formation involves a remarkable sequence of events. A pollen grain must first reach the stigma, germinate, produce a pollen tube and successfully travel through the pistil to deliver the male gametes to the ovule. Only when all these events occur in a coordinated manner can successful fertilization and seed formation take place. Although pollination may appear to be a simple event, it is actually the beginning of a complex molecular communication between the pollen and the pistil. The stigma acts as an important recognition site, where compatible pollen is accepted while incompatible pollen may be rejected. This recognition involves receptors, signaling molecules, proteins, hormones, calcium signals and reactive oxygen species. These molecular signals regulate pollen hydration, germination and subsequent pollen tube growth (Zakharova *et al.*, 2025). Understanding this hidden communication is important not only from a biological perspective but also for agriculture. Knowledge of the genes, proteins and signaling pathways involved in pollen recognition, pollen tube guidance and fertilization can help researchers develop efficient hybrid breeding systems and improve seed production.

## What Happens When Pollen Reaches the Stigma?

The first step in this remarkable journey is the interaction between the pollen grain and the stigma. Stigmas are broadly classified into wet and dry types depending on the presence or absence of surface secretion. A wet stigma contains a fluid-like secretion rich in water, lipids, proteins, carbohydrates and signaling molecules. This secretion helps the pollen grain adhere to the stigma, absorb water and begin germination. In contrast, a dry stigma does not have an obvious surface secretion. Instead, pollen recognition and compatibility depend more strongly on specific molecular interactions between pollen-coat components and molecules present on the stigmatic surface. The developmental stage of pollen also influences its reproductive behaviour. Pollen may be released at the binucleate or trinucleate stage. These differences determine the developmental status of the male gametophyte and influence pollen germination, pollen tube growth and ultimately fertilization (Amanda *et al*., 2022).

## From a Tiny Pollen Grain to a Growing Pollen Tube

Once compatible pollen is recognized and hydrated, it germinates and produces a pollen tube. This tube acts like a biological pathway through which the male gametes travel towards the ovule. The pollen tube is not simply a hollow structure. It is a highly specialized and polarized growing cell. Its tip, or apex, is the most active region, where new cell-wall materials are continuously delivered and incorporated. Behind the tip lies the older shank, which becomes progressively stronger and provides mechanical support to the growing tube. This type of growth is known as tip growth. Unlike ordinary cells that expand over a larger surface, the pollen tube mainly extends at its growing tip. This allows it to move forward through the female reproductive tissues while maintaining its characteristic tubular shape (Cheung *et al*., 2008).

## A Flexible Tip and a Stronger Shank

One of the most interesting features of the pollen tube is that different regions of its cell wall have different properties. The apex needs to remain flexible because it must continuously expand as the pollen tube grows. The cell wall in this region is highly dynamic and undergoes continuous secretion, modification, loosening, expansion and reinforcement. Pectin is particularly important in maintaining the flexibility required for tip growth. In contrast, the older shank requires greater mechanical strength. Components such as callose, pectin and other structural polysaccharides contribute to the stability and reinforcement of this region. Thus, the pollen tube can be viewed as a structure with a soft, actively growing tip and a stronger supporting body reported by Mollet *et al*. (2013).

## Pectin: The Flexible Building Material

Pectin is an important component of the pollen tube cell wall. Its chemical state can change during pollen tube growth. Two important forms shown in the figure are esterified pectin and de-esterified pectin. Highly esterified pectin generally contributes to a more flexible and extensible cell wall, which is particularly important at the growing pollen tube tip. When pectin becomes de-esterified, it can interact with calcium ions. Calcium-mediated interactions can strengthen the pectin network and increase cell-wall rigidity. Therefore, the correct balance between esterified and de-esterified pectin is essential for maintaining controlled pollen tube growth (Cascallares *et al*., 2020).

## PME and PMEI: The Molecular Regulators

The modification of pectin is controlled by important enzymes and their regulators. **Pectin methylesterase (PME)** removes methyl groups from methyl-esterified pectin, converting it into a more de-esterified form:

**Esterified pectin → PME action → De-esterified pectin**

The resulting de-esterified pectin can interact with calcium ions and contribute to cell-wall strengthening. However, too much de-esterification may make the wall excessively rigid and interfere with pollen tube extension. Therefore, PME activity must be carefully controlled.

This is where **pectin methylesterase inhibitor (PMEI)** becomes important. PMEI inhibits PME activity and thereby helps regulate the extent of pectin de-esterification:

**PMEI → inhibits PME → maintains higher esterified pectin**

The coordinated action of PME and PMEI helps the pollen tube maintain the right balance between **flexibility and strength** during growth (Xie *et al*., 2026).

## Callose: Strengthening the Pollen Tube

Another important component of the pollen tube wall is callose, a β-1,3-glucan polysaccharide. Callose contributes to mechanical strength, structural stability and maintenance of pollen tube shape. Its deposition is more prominent in the shank and subapical regions, whereas the extreme tip remains highly dynamic and relies strongly on pectin-mediated wall remodeling. This difference between the tip and shank allows the pollen tube to grow forward without losing its structural integrity (Hao *et al*., 2023).

## Tiny Vesicles Driving Pollen Tube Growth

How does the pollen tube continuously obtain the materials needed for growth? The answer lies partly in vesicle trafficking. The figure shows two types of vesicles: exocytotic vesicles and endocytotic vesicles. Exocytotic vesicles transport newly synthesized materials towards the pollen tube tip. These materials may include pectins, cell-wall polysaccharides, enzymes and membrane components. When these vesicles fuse with the plasma membrane, their contents are released into the cell-wall region. Endocytotic vesicles, on the other hand, help remove and recycle portions of the plasma membrane and associated materials. This recycling helps regulate membrane surface area and maintain the shape of the growing pollen tube. Therefore, exocytosis and endocytosis work together like a delivery and recycling system, allowing the pollen tube to grow continuously at its tip (Zhao *et al*., 2020).

## The Molecular Journey Towards the Ovule

The pollen tube must successfully navigate through the pistil to reach the ovule. During this journey, pollen–pistil communication continues to guide and regulate its growth. The entire process involves a coordinated sequence:

**Pollen germination → pollen tube emergence → vesicle trafficking → secretion of cell-wall materials → pectin modification → regulation by PME and PMEI → cell-wall strengthening → controlled pollen tube growth**

This carefully regulated process allows the pollen tube to remain flexible at its growing tip while maintaining sufficient strength in its older regions (Cascallares *et al*., 2020).

## Why Does Pollen–Pistil Interaction Matter?

Pollen–pistil interaction is much more than the simple transfer of pollen from anther to stigma. It is a sophisticated communication system that determines whether pollen is accepted, whether it can germinate and whether the pollen tube can successfully reach the ovule. The genetic mechanisms controlling pollen recognition, pollen tube guidance and fertilization are therefore important for understanding reproductive compatibility and reproductive barriers. They also have considerable applications in agriculture, particularly in hybrid seed production, reproductive manipulation and improvement of seed productivity (Broz *et al*., 2021).

## A Hidden World Inside a Pollen Tube

The pollen tube may look like a tiny microscopic structure, but its growth involves an extraordinary level of coordination. Pectin provides flexibility, callose contributes to strengthening, PME modifies pectin, PMEI regulates PME and vesicles continuously deliver and recycle materials at the growing tip. Thus, the pollen tube cell wall is not a static protective covering. It is a highly dynamic structure that continuously changes its composition and mechanical properties as the pollen tube elongates. Understanding this microscopic journey provides a fascinating insight into how flowering plants reproduce and, at the same time, opens opportunities for improving crop reproductive efficiency, hybrid seed production and seed quality.

## Future Perspectives

The study of pollen–pistil interaction provides exciting opportunities for understanding and improving plant reproductive efficiency. Future research should focus on identifying the genes, proteins, receptors and signaling molecules that regulate pollen recognition, pollen tube growth and guidance. Advances in genomics, transcriptomics, proteomics and live-cell imaging can help reveal the molecular events occurring during pollen–pistil communication in greater detail. Particular attention should be given to the regulation of pectin methylesterase (PME), pectin methylesterase inhibitor (PMEI), calcium signaling, callose deposition and vesicle trafficking, as these processes are essential for maintaining the balance between pollen tube flexibility and mechanical strength. Understanding these mechanisms may also help researchers manipulate pollen compatibility, overcome reproductive barriers and improve fertilization efficiency. Such knowledge could contribute to the development of efficient hybridization systems, improved hybrid seed production and climate-resilient crops. Integrating molecular knowledge with modern breeding and biotechnology approaches may ultimately provide new strategies for improving crop productivity and seed quality.

## Conclusion

Pollen–pistil interaction is a highly sophisticated molecular communication process that determines the success of fertilization and seed formation in flowering plants. From pollen recognition and hydration at the stigma to pollen tube growth and guidance towards the ovule, every stage involves precise coordination between cellular, biochemical and molecular signals. The dynamic pollen tube cell wall plays a particularly important role, with pectin providing flexibility, callose contributing to structural strength, PME modifying pectin and PMEI regulating PME activity. At the same time, vesicle trafficking continuously supplies and recycles the materials required for pollen tube elongation. Thus, the pollen tube is not merely a passage for male gametes but a highly dynamic and precisely regulated structure. Understanding this remarkable molecular conversation can provide valuable insights into plant reproductive biology and offer practical opportunities for improving hybrid breeding, seed production and crop productivity. The study of pollen–pistil interaction therefore represents an important link between fundamental plant biology and future agricultural innovation.

## References

1. Amanda, Dhika, Felix P. Frey, Ulla Neumann, Marine Przybyl, Jan Šimura, Youjun Zhang, Zongliang Chen et al. "Auxin boosts energy generation pathways to fuel pollen maturation in barley." *Current Biology* 32, no. 8 (2022): 1798-1811.
2. Broz, Amanda K., and Patricia A. Bedinger. "Pollen-pistil interactions as reproductive barriers." *Annual Review of Plant Biology* 72, no. 1 (2021): 615-639.
3. Cascallares, Milagros, Nicolás Setzes, Fernanda Marchetti, Gabriel Alejandro López, Ayelén Mariana Distéfano, Maximiliano Cainzos, Eduardo Zabaleta, and Gabriela Carolina Pagnussat. "A complex journey: cell wall remodeling, interactions, and integrity during pollen tube growth." *Frontiers in Plant Science* 11 (2020): 599247.
4. Hao, Guang-Jiu, Lu-Shen Li, Xin-Ying Zhao, Jun Ying, Miao-Miao Zhang, Xue-Chun Cui, Tiantian Sun et al. "Canonical Rab5 GTPases are essential for pollen tube growth through style in Arabidopsis." *New Phytologist* 239, no. 5 (2023): 1740-1753.
5. Mollet, Jean-Claude, Christelle Leroux, Flavien Dardelle, and Arnaud Lehner. "Cell wall composition, biosynthesis and remodeling during pollen tube growth." *Plants* 2, no. 1 (2013): 107-147.
6. Xie, Minmin, Xiaodong Xie, Jingjing Mao, Zhiyuan Li, Mingli Chen, Yingzhen Kong, Zhen Tian, Daping Gong, and Jinhao Sun. "Advances in the functional research of pectin methylesterases in Arabidopsis thaliana." *BMC Plant Biology* 26, no. 1 (2026): 949.

7. Zakharova, Ekaterina V., Alexej I. Ulianov, Yaroslav Yu Golivanov, Tatiana P. Molchanova, Yuliya V. Orlova, and Oksana A. Muratova. "Pollen–pistil interaction during distant hybridization in plants." *Agronomy* 15, no. 7 (2025): 1732.
8. Zhao, Lifeng, Muhammad Saad Rehmani, and Hao Wang. "Exocytosis and endocytosis: Yin Yang crosstalk for sculpting a dynamic growing pollen tube tip." *Frontiers in plant science* 11 (2020): 572848.