From developmental signalling to reproductive resilience: Expanding the functional landscape of RGF peptides

Tengyu Li[1] **and Yazhong Wang**[1,2,*]
[1]Laboratory of Advanced Breeding Technologies, Institute of Genetics and Developmental Biology, Chinese Academy of Sciences, Beijing 100101, China
[2]College of Advanced Agricultural Sciences, University of Chinese Academy of Sciences, Beijing 101408, China
*Correspondence: wangyazhong@genetics.ac.cn
Received: June 8, 2026; Accepted: August 19, 2026; Published Online: August 24, 2026; https://doi.org/10.59717/j.xinn-life.2026.100244

Citation: Li T. and Wang Y. (2026). From developmental signalling to reproductive resilience: Expanding the functional landscape of RGF peptides. *The Innovation Life* **4**:100244.

MAINTEXT

Climate change is increasingly exposing crop reproduction to transient yet severe environmental fluctuations. Among these challenges, episodic chilling events during pollen development can dramatically compromise fertility and yield.[1,2] In this issue, *Chen et al.* report a chilling-induced ROOT GROWTH FACTOR (RGF) signaling pathway that safeguards tapetal degeneration, pollen viability, and crop productivity under cold stress.[3] By uncovering an unexpected role for RGF peptides in reproductive stress adaptation, this study substantially expands the functional repertoire of peptide signaling beyond its established developmental functions. More broadly, the work suggests that peptide-mediated signaling may contribute to maintaining developmental robustness under environmental perturbation. Here, we discuss how the tomato SlRGF-SlRGFR6-Ca^{2+} module may function as a developmental buffering system that stabilizes reproductive developmental trajectories during transient cold episodes. This concept resonates with Waddington's classical framework of developmental canalization, whereby biological systems maintain stable developmental outcomes despite environmental variation. We further propose that this pathway may represent part of a broader environmental peptide signaling network that translates external cues into adaptive developmental responses. Finally, we suggest that genes such as RGF signaling components exemplify a class of "conditional resilience genes", whose importance becomes evident only under specific environmental challenges. As climate instability increasingly threatens agricultural productivity, engineering reproductive resilience rather than simply enhancing stress tolerance may emerge as a central objective of future crop improvement (Figure 1).

Beyond development: A new role for RGF peptides

RGF/GLV (GOLVEN)/CLEL (CLAVATA3-ESR-related like) peptides have long been recognized as regulators of plant development.[4] RGF/GLV/CLEL peptides belong to the family of plant small signalling peptides (SSPs), which are secreted peptide hormones generated from precursor proteins through proteolytic processing. Mature SSPs are typically only 10-20 amino acids long and function extracellularly by binding plasma membrane receptor kinases, in contrast to canonical proteins that generally act as folded intracellular or extracellular proteins. In Arabidopsis, RGF signalling controls root meristem maintenance, organ growth, and developmental patterning through interactions between RGF receptors and SERK co-receptors. Consequently, the RGF pathway has largely been viewed as a developmental signaling module that coordinates cellular behavior during organ formation.

The study by *Chen et al.* substantially broadens this perspective.[3] Through an integrative approach combining transcriptomics, genetics, structural biology, peptide biochemistry, calcium imaging, and field validation, the authors identified two tomato RGF peptides, SlRGF9 and SlRGF10, that are strongly induced by chilling stress during pollen development. These peptides activate a receptor complex consisting of SlRGFR6 and SlSERK co-receptors, leading to calcium influx through cyclic nucleotide-gated channels (SlCNGC16 and SlCNGC18). The resulting calcium signal promotes timely tapetal programmed cell death (PCD), thereby preserving pollen viability and maintaining reproductive success under cold conditions.

Notably, the *Slrgf9 Slrgf10* loss-of-function double mutants display only modest phenotypes under optimal growth conditions but exhibit severe reproductive defects under chilling stress.[3] Rather than determining developmental fate, the RGF signaling module appears to become critical when environmental perturbation threatens the successful progression of reproductive development. Interestingly, *Chen et al.* further revealed functional redundancy between SlRGF9 and SlRGF10, together with a dosage-dependent effect on reproductive resilience. Moderate enhancement of RGF expression improved stress performance, whereas excessive expression could become detrimental, indicating that reproductive robustness depends on finely tuned peptide signaling rather than maximal pathway activation.[3] This conditional requirement distinguishes the pathway from many classical developmental regulators and points to a broader role for peptide signaling in safeguarding developmental processes under stress.

Developmental buffering: Canalization of reproductive development

The most profound implication of this study may lie not simply in the identification of a new signaling pathway, but in the biological principle it reveals. Plant development is often depicted as the outcome of highly coordinated genetic programs. Yet reproductive development rarely occurs under stable environmental conditions. In natural and agricultural ecosystems alike, developing reproductive tissues continuously encounter fluctuations in temperature, water availability, and other environmental variables. Therefore, successful reproduction depends not only on developmental regulation itself, but also on mechanisms that preserve developmental trajectories when environmental conditions become unfavorable.

The RGF pathway identified by *Chen et al.* appears to function in precisely this capacity. Rather than initiating a new developmental process, RGF signaling stabilizes an existing one. Chilling stress delays tapetal degeneration and consequently disrupts pollen maturation. Activation of the SlRGF-SlRGFR6-Ca^{2+} pathway counteracts this disturbance by restoring the timing of tapetal PCD and enabling normal pollen development.[3]

This interpretation evokes Waddington's concept of developmental canalization, in which biological systems maintain stable phenotypic outcomes despite genetic or environmental perturbations.[5] As illustrated in Figure 1, environmental stress can divert reproductive development away from its optimal trajectory, whereas activation of the RGF signaling module acts as a buffering mechanism that redirects development toward its intended outcome. In this sense, RGF signaling functions as a developmental buffering system that preserves reproductive robustness under stress.

More broadly, these findings encourage a shift in how stress adaptation is conceptualized. Rather than viewing stress-response pathways solely as defence systems that mitigate cellular damage, some stress-response pathways may primarily function to preserve developmental fidelity when environmental fluctuations threaten key developmental transitions. Such buffering mechanisms may represent an underappreciated layer of reproductive regulation operating alongside canonical developmental pathways.[3,5]

Reproductive resilience as an emerging breeding paradigm

The translational implications of this work are equally noteworthy. Traditional breeding for abiotic stress tolerance frequently encounters a fundamental challenge: enhanced stress resistance often comes at the expense of growth and productivity under favorable conditions. Constitutive activation of stress-responsive pathways can impose metabolic costs or disrupt normal development, creating undesirable trade-offs.

The RGF pathway may offer an alternative strategy. Because its contribution becomes particularly important under chilling conditions while requiring appropriate expression levels to maximize reproductive performance, it resembles what might be termed a conditional resilience module. Rather than enhancing stress resistance via constitutive defence activation, the pathway selectively shields reproductive development when environmental conditions endanger fertility.

This distinction suggests a conceptual shift for future crop improvement. Instead of focusing exclusively on stress tolerance, breeders may increasingly seek to enhance reproductive resilience—the capacity to maintain fertility, seed set, and yield stability under fluctuating environmental conditions. The

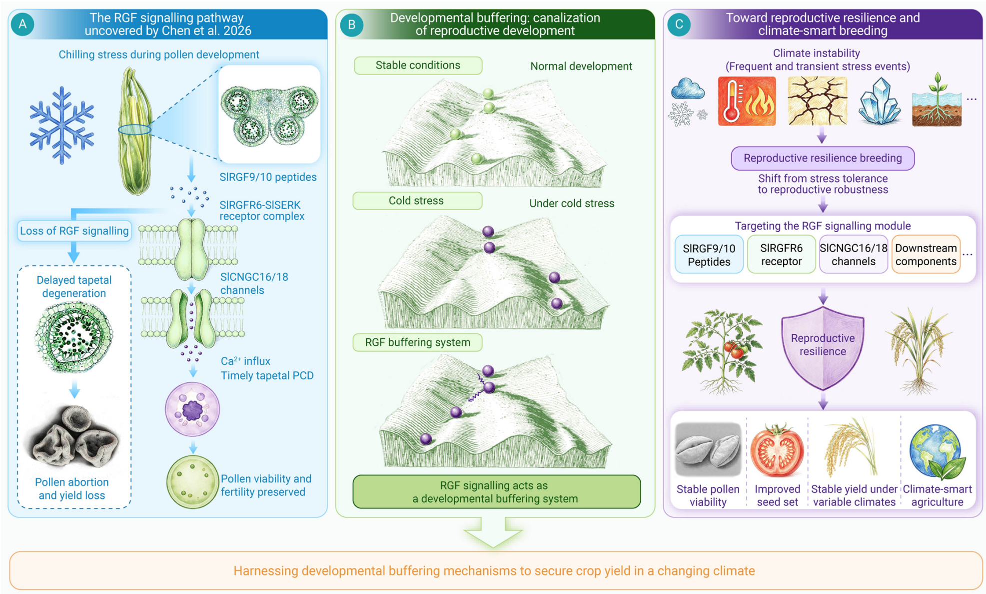

Figure 1. RGF signalling as a developmental buffering mechanism for reproductive resilience under environmental stress Climate instability increasingly exposes developing reproductive tissues to transient environmental perturbations, particularly chilling stress during pollen development. Cold-induced SlRGF9/10 peptides activate the SlRGFR6-SlSERK receptor complex and stimulate SlCNGC16/18-mediated Ca^{2+} influx, promoting timely tapetal programmed cell death (PCD) and preserving pollen viability. Loss of RGF signalling delays tapetal degeneration and compromises reproductive success under chilling conditions. Beyond this molecular mechanism, we propose that the RGF-RGFR6-Ca^{2+} pathway functions as a developmental buffering system that stabilizes reproductive developmental trajectories when environmental fluctuations threaten developmental fidelity. Within a canalization framework, environmental stress can divert development from its optimal trajectory, whereas RGF signalling acts to maintain developmental robustness and reproductive success. The conservation of this pathway across crop species highlights its potential value for breeding strategies aimed at improving reproductive resilience, yield stability, and climate adaptation in future agriculture. Abbreviations: *Sl*, *Solanum lycopersicum*; RGF, ROOT GROWTH FACTOR; RGFR6, RGF receptor 6; SERK, SOMATIC EMBRYOGENESIS RECEPTOR KINASE; CNGC, cyclic nucleotide-gated channel; PCD, programmed cell death.

successful enhancement of cold resilience in both tomato and rice reported by *Chen et al.* demonstrates the translational potential of this strategy.[3] Under chilling conditions, transgenic tomato lines overexpressing SlRGF9 or SlRGF10 rescued approximately 33.9-52.2% of the chilling-induced yield losses, whereas optimized expression of OsRGF10 in rice prevented nearly 18% of grain yield reduction under field conditions.[3] These substantial gains highlight the practical value of targeting reproductive resilience pathways for climate adaptation.

More generally, the study raises the possibility that many genes with limited phenotypic effects under standard laboratory conditions may nevertheless play indispensable roles in maintaining fitness under environmental stress. Such genes could be viewed as conditional resilience genes, whose functions become apparent only under specific environmental challenges. Identifying and harnessing this class of genes may provide new opportunities for climate-smart crop breeding.

Outstanding questions

Like many significant discoveries, this work raises several outstanding questions. First, the upstream chilling sensor remains unknown. Although the authors identify a signaling pathway activated by low temperature, the mechanism through which reproductive tissues initially perceive chilling remains elusive. Understanding how temperature information is converted into RGF expression represents a critical next step.

Second, the molecular connection between calcium influx and tapetal PCD requires further investigation. Calcium clearly functions as a key intermediary, but the downstream transcriptional and cellular events linking calcium signaling to developmental timing remain largely unexplored.

Third, it remains unclear whether similar peptide-mediated buffering systems operate under other environmental stresses. Are there drought-responsive, heat-responsive, or salinity-responsive peptide networks that stabilize reproductive development in analogous ways? If so, plants may possess an extensive repertoire of environmentally responsive peptide signaling networks that coordinate developmental resilience across diverse stress conditions.

Finally, the relationship between RGF signaling and established reproductive pathways, including EMS1-TPD1 signaling, tapetal specification networks, and meiotic regulatory programs, remains unresolved. Understanding how environmental buffering pathways integrate with core developmental circuits will be essential for constructing a comprehensive model of reproductive resilience.

Concluding remarks and towards future breeding

The discovery of chilling-responsive RGF signaling considerably expands the biological significance of peptide hormones beyond their established developmental functions. By revealing a mechanism that preserves reproductive development under adverse environmental conditions, Chen and colleagues provide compelling evidence that peptide signaling can act not only as a regulator of development but also as a stabilizer of developmental outcomes.

More broadly, this work highlights an emerging principle in plant biology: successful reproduction depends not only on developmental programs themselves, but also on specialized mechanisms that buffer those programs against environmental uncertainty.[3,5] As crop improvement increasingly shifts toward climate adaptation, maintaining reproductive resilience may become one of the defining challenges of next-generation breeding. The RGF pathway described here provides both a conceptual framework and a molecular entry point for achieving this goal, illustrating how developmental buffering mechanisms may be harnessed to secure crop productivity in an increasingly unpredictable climate.

REFERENCES

1. Hedhly A., Hormaza J.I., and Herrero M. (2009). Global warming and sexual plant reproduction. *Trends Plant Sci.* **14**:30–36. DOI:10.1016/j.tplants.2008.11.001
2. Zinn K.E., Tunc-Ozdemir M., and Harper J.F. (2010). Temperature stress and plant sexual reproduction: Uncovering the weakest links. *J. Exp. Bot* **61**:1959–1968. DOI:10.1093/jxb/erq053
3. Chen S., Zou Y., Cui H., et al. (2026). Cold-induced peptide signalling secures pollen resilience and crop yield. *Nature* **656**:173–182. DOI:10.1038/s41586-026-10603-7
4. Hastwell A.H., Chu X., Liu Y., et al. (2024). The parallel narrative of RGF/GLV/CLEL peptide signalling. *Trends Plant Sci.* **29**:1342–1355. DOI:10.1016/j.tplants.2024.07.014
5. Waddington C.H. (1942). Canalization of development and the inheritance of acquired characters. *Nature* **150**:563–565. DOI:10.1038/150563a0

FUNDING AND ACKNOWLEDGMENTS

The authors acknowledge support from the 'BR Talents Program' of Chinese Academy of Sciences (No. E5651L01), the Excellent Young Scientists Fund (Overseas) of the National Natural Science Foundation of China (E5101L01), the General Program of National Natural Science Foundation of China (3257020943) and CAS Project for Young Scientists in Basic Research (Grant No. YSBR-134). We apologize to those authors whose work, although contributing to the development of this field, could not be cited that due to space constraints. The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

AUTHOR CONTRIBUTIONS

T.L. and Y.W. conceived and drafted the manuscript. All authors contributed to the manuscript and approved the final version.

DECLARATION OF INTERESTS

The authors declare no competing interests.