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Can the Environment Directly Rewrite Inheritance?

Taolan Zhao[1] | Wenfeng Qian[2,3]

[1]Wiley-VCH GmbH, Weinheim, Germany | [2]State Key Laboratory of Seed Innovation, Institute of Genetics and Developmental Biology, Chinese Academy of Sciences, Beijing, China | [3]University of Chinese Academy of Sciences, Beijing, China

Correspondence: Taolan Zhao (tzhao@wiley.com) | Wenfeng Qian (wfqian@genetics.ac.cn)

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More than two centuries ago, the French naturalist Jean-Baptiste Lamarck put forward a bold idea: what if the experiences of an organism during its lifetime could be passed on to its offspring? Imagine a giraffe stretching its neck to reach higher leaves and then giving birth to longer-necked babies—this was the kind of evolutionary thinking Lamarck proposed. Though imaginative and ahead of his time, Lamarck's theory clashed with the emerging Darwinian model, which explained evolution through random genetic mutations and natural selection. Without molecular evidence, Lamarckism was eventually dismissed by mainstream science—until now, as new research begins to revisit some of its core ideas through the lens of epigenetics.

In recent years, the discovery of transgenerational epigenetic inheritance—heritable changes that affect gene expression without altering DNA sequences—has revived interest in Lamarckian evolution. Epigenetic changes can be triggered by environmental cues, and involve modifications such as DNA methylation, which influence how genes are expressed. Epigenetic inheritance was seen as a potential support for Lamarckism because it provides a mechanism by which environmental experiences of an organism could influence offspring phenotypes.

However, these interpretations of epigenetic mechanisms as Lamarckian were often problematic. Classical Lamarckism considered the inheritance of acquired characteristics as inherent in living matter itself and capable of driving unlimited evolutionary change. Conversely, modern transgenerational epigenetic inheritance mechanisms are inherently limited in their capacity for long-term adaptive evolution because of the instability and reversibility of epigenetic marks. Moreover, classical Lamarckism requires that adaptive traits be directly induced by specific environmental conditions and then inherited. However, most studies on epigenetic inheritance have not provided strong evidence linking environmental triggers to beneficial, heritable changes.

In a groundbreaking study by Xiaofeng Cao and colleagues [1], researchers have provided the first clear molecular evidence of stable transgenerational epigenetic inheritance of adaptive traits in rice. They demonstrated that DNA hypomethylation in the Acquired Cold Tolerance 1 (*ACT1*) promoter region was induced by cold stress, rendering *ACT1* gene expression insensitive to cold temperatures. This epigenetic alteration provided the plants with stable, heritable cold tolerance, an adaptation crucial for the northward expansion of rice cultivation from tropical origins (Figure 1).

This study marks a significant milestone as it is the first demonstration that environmentally-altered beneficial traits can be stably inherited across multiple generations in the absence of the initial environmental trigger, conferring clear adaptive advantages. Expert in epigenetics, Prof. Bing Zhu from the Institute of Biophysics, Chinese Academy of Sciences, emphasises, 'Cytosine DNA methylation is probably the best candidate for transgenerational epigenetic inheritance because of its high maintenance efficiency through cell divisions.'

These findings suggest important implications for understanding adaptive evolutionary processes, highlighting mechanisms beyond classical Darwinian evolution. Epigenetic inheritance can rapidly confer advantageous traits significantly faster than traditional genetic mutations. However, an evolutionary geneticist Prof. Jianzhi Zhang from the University of Michigan points out, 'Though epigenetic inheritance can quickly provide adaptive traits, its inherent instability prevents it from playing a major role in long-term evolutionary adaptation compared to stable genetic mutations.'

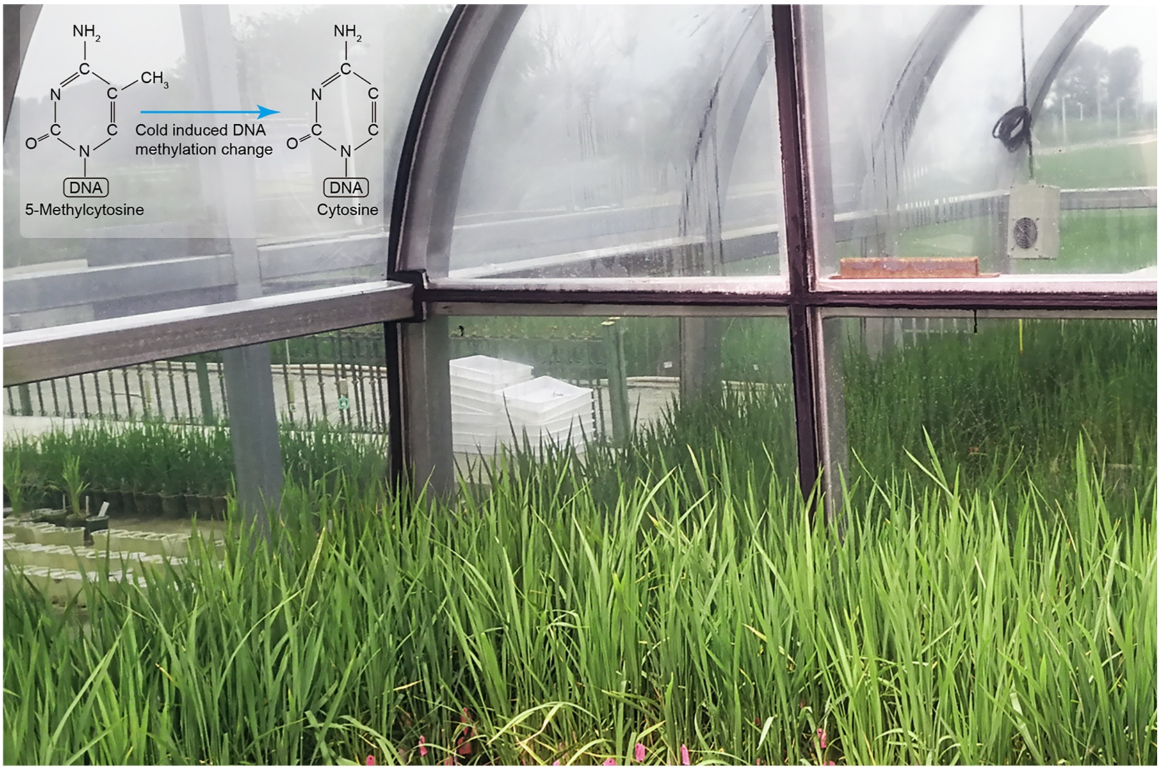

FIGURE 1 | How rice plants remember the cold over generations. When exposed to cold for a few generations, rice can 'remember' the experience by changing tiny chemical marks (called DNA methylation) on particular genes. This change helps the plants tolerate cold better, and the memory can be passed on to their offspring—even when grown in normal conditions. The image shows rice in a greenhouse experiment demonstrating this remarkable ability to inherit acquired environmental adaptations.

The discovery holds considerable promise for agricultural applications. By harnessing epigenetic modifications, crops could be rapidly adapted to changing climates without lengthy breeding programs. Prof. Kang Chong from the Institute of Botany, Chinese Academy of Sciences explains, 'Epigenetic editing tools could enable breeders to induce beneficial traits such as drought resistance or cold tolerance within a few generations, significantly enhancing crop resilience and productivity.'

As Prof. Cao's team suggests, these findings may inspire a broader rethink of how rapid adaptation can occur in plants and possibly other organisms using epigenetic mechanisms, offering a flexible and responsive layer to evolutionary dynamics in an era of climate uncertainty.

Author Contributions

Taolan Zhao: conceptualisation, writing – original draft. **Wenfeng Qian:** conceptualisation, writing – original draft.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

Data sharing not applicable to this article as no datasets were generated or analysed during the current study.

Reference

1. Song et al., "Inheritance of Acquired Adaptive Cold Tolerance in Rice through DNA Methylation," *Cell* (2025): DOI: 10.1016/j.cell.2025.04.036.