How grasses like wheat can grow in the cold

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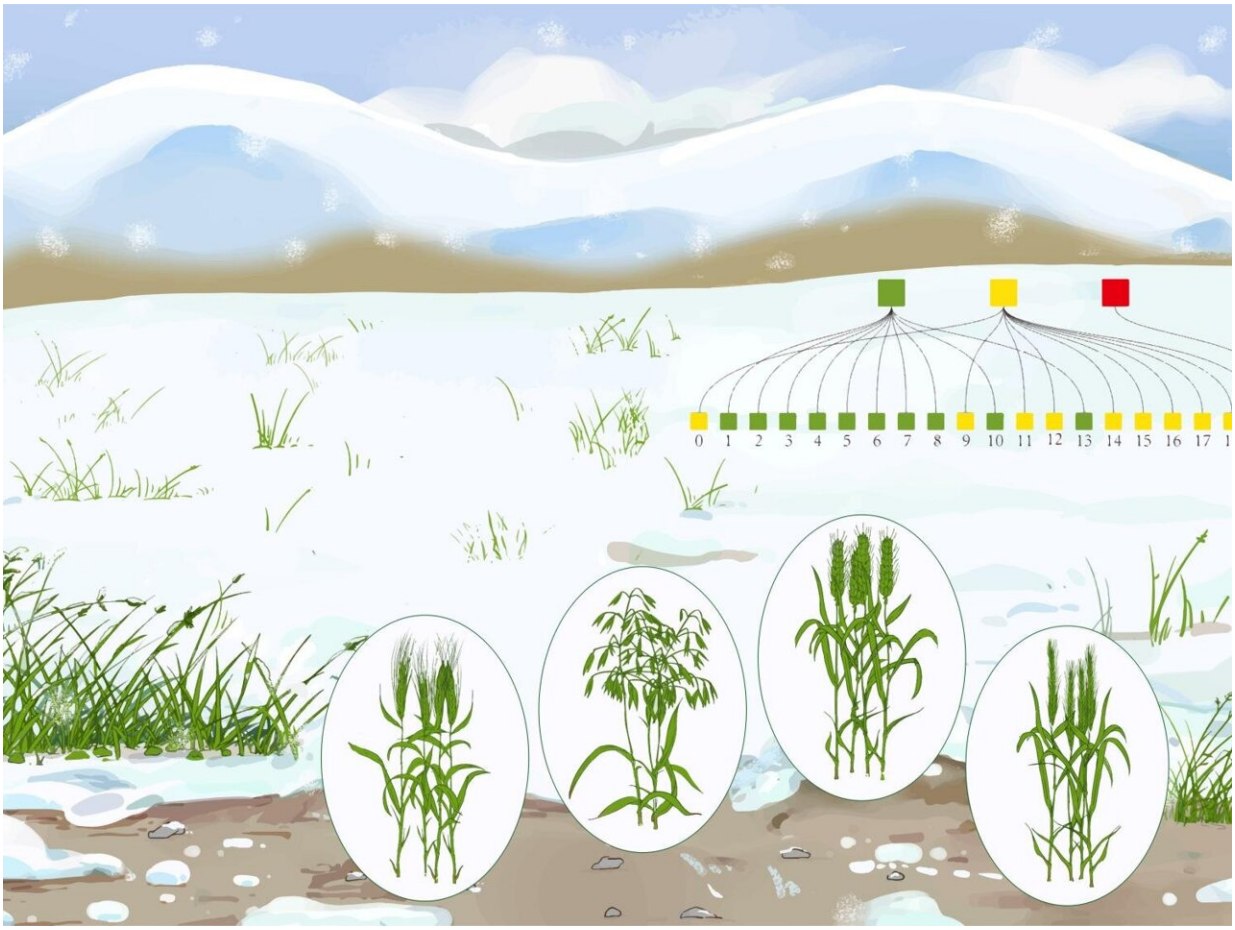

New study of the relationships among members of the largest subfamily of grasses reveals gene-duplication events (represented by colored boxes) that contributed to the adaptation of the plants to cooler temperatures. Credit: Lin Zhang

A new, large-scale analysis of the relationships among members of the largest subfamily of grasses, which includes wheat and barley, reveals gene-duplication events that contributed to the adaptation of the plants to cooler temperatures. These adaptations allowed the grasses to thrive in temperate climates and have been exploited by humans to extend the range and season for growing important crop plants. A paper describing the study, led by Penn State scientists, appears online in the journal *Molecular Biology and Evolution*.

"Grasses are the fifth largest family of plants with over 11,000 species," said Hong Ma, Dorothy Foehr Huck and J. Lloyd Huck Chair of Plant Reproductive Development and Evolution and professor of biology at Penn State and the leader of the research team. "They grow natively on all seven continents, including one of two native flowering plants on Antarctica. Many members of the largest subfamily of grasses, known as Pooideae, have adapted to grow in temperate environments. To investigate potential factors that led to this cool adaptation, we performed an analysis of the Pooideae family tree using a large set of nuclear genes."

The research team compared transcriptomes—DNA sequences of all of the genes expressed by an organism—from 157 Pooideae species covering nearly all of the major subdivisions within the subfamily.

"This group of grasses started expanding about 50 million years ago when the Earth was in a cooling period," said Ma. "The Earth was much warmer then, but the plants and animals were much different as well. These grasses were able to flourish because they could adapt to the changing environment. All of the major subdivisions within the subfamily—called tribes—were established in the first part of this cooling period. Later there was another large expansion which led to major diversification at the species level. Today's success of this subfamily of around 4,000 species, benefited from its ability to adapt

when the Earth was cooling."

How were these grasses able to adapt so well to the changing environment? They developed traits better suited to colder temperatures, including flowers with different shapes and sizes, cold-dependent flowering, and molecular adaptations that reduce cellular freezing. All of these changes rely on genetic innovation.

A major source of genetic innovation is gene duplication. Gene duplication can occur when errors during genome replication or recombination result in extra copies of genes. These extra copies are often functionally redundant to the original copies of the gene and can therefore tolerate mutations more freely. Often, they are mutated to the point of losing their function all together, but sometimes these mutations can lead to functional innovations.

"Our study of the relationships among the species in this subfamily of grasses allowed us to trace adaptive changes relative to geologic and climate changes," said Ma. "It also allowed us to identify gene duplications that occurred over time and likely supported this adaptation."

One example of gene duplication which likely aided in the cold adaptation of these grasses are CBF genes. Molecular studies have demonstrated a role for CBF and related genes in a plant's ability to tolerate freezing. The researchers show that the earliest members of the Pooideae subfamily likely had three copies of these genes. Modern barley has 20 and wheat has 37. Another example is the AP1/FUL genes which are involved in vernalization—the ability of plants to cope with seasonal changes and long, cold winters and have experienced similar duplications in Pooideae.

"We can track when these duplication events occurred in the Pooideae

family tree and associate them with environmental changes to better understand the process of cold adaptation in these grasses," said Ma. "As we are now experiencing another period of global environmental change, understanding how plants adapt to this kind of change may be more important than ever."

More information: Lin Zhang et al, Phylotranscriptomics Resolves the Phylogeny of Pooideae and Uncovers Factors for Their Adaptive Evolution, *Molecular Biology and Evolution* (2022). DOI: 10.1093/molbev/msac026

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