Borrowed gene helps maize adapt to high elevations, cold temperatures

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Researchers at North Carolina State University show that an important gene in maize called HPC1 modulates certain chemical processes that contribute to flowering time, and has its origins in "teosinte mexicana," a precursor to modern-day corn that grows wild in the highlands of Mexico. The findings provide insight into plant evolution and trait selection, and could have implications for corn and other crops' adaptation to low temperatures.

"We are broadly interested in understanding how natural variation of lipids are involved in the growth and development of plants, and how these compounds may help plants adapt to their immediate environments," said Rubén Rellán-Álvarez, assistant professor of structural and molecular biochemistry at NC State and the corresponding author of a paper describing the research. "Specifically, we wanted to learn more about variation in lipids called phospholipids, which consist of phosphorus and fatty acids, and their role in adaptation to cold, low phosphorus, and the regulation of important processes for plant fitness and yield like flowering time."

Maize grown at higher altitudes, like the highlands of Mexico, needs special accommodations in order to grow successfully. The colder temperatures in these mountainous regions put maize at a slight disadvantage when compared with maize grown at lower elevations and higher temperatures.

"At high elevations, in colder temperatures, it takes longer to make a maize plant due to lower heat unit accumulation—corn needs to accumulate heat or growth units," Rellán-Álvarez said. "At 10,000 feet (2,600 meters), it takes three times longer to make a maize plant than at lower elevations. To adapt to these special conditions, campesinos—smallholder farmers—must plant early in the season and plant deep in the soil; there is very slow but steady growth in earlier months until the rainy season arrives. Over millennia, campesinos have selected maize varieties that can thrive in these special conditions by being able to grow at low temperatures and flower early before the colder months arrive in the winter."

That's where the HPC1 gene comes in, the researchers say. In corn varieties grown in low elevations, including most of the corn grown in the United States, the gene breaks down phospholipids that in other species have been shown to bind to important proteins that accelerate flowering time.

"Phospholipids are also important building blocks of cell membranes. All lipids have different shapes and balancing these shapes is what allows membranes to stay intact and helps plants to survive periods of stress," said Allison Barnes, a postdoctoral researcher in Rellán-Álvarez's lab and co-first author of the paper.

In the mountains, though, the gene misfires, but to the benefit of highland maize.

"In highland maize, a defective version of the gene was selected and this led to high levels of phospholipids," Rellán-Álvarez said. "We developed a CRISPR-Cas9 mutant and confirmed the metabolic function of the gene. We also showed similar phospholipid-protein interactions that had been described in other species to regulate flowering time."

"The phospholipids that are not broken down in the highlands may be better for keeping membranes together, allowing the plant to survive the adverse environment," Barnes added.

In the paper, the researchers show the results of vast experiments throughout Mexico—in lowlands and highlands—in which the highland version of the gene was present. They found that corn with the highlands version of the gene flowered one day earlier than plants without that version of the gene. Meanwhile, corn grown in the lowlands with the highlands version of the gene flowered one day later than plants without that gene version.

"It's helping the plant do better in its local environment," said Fausto Rodríguez-Zapata, a Ph.D. student in Rellán-Álvarez's lab and co-first author of the paper. "If flowering doesn't work, there will be no seed, so it's not surprising that something involved in flowering time is also involved in local adaptation."

The study also examined maize's evolution through thousands of years of farmer selection throughout the Western Hemisphere. Native Americans domesticated maize thousands of years ago in southwest Mexico from a wild plant called teosinte parviglumis, and with great ingenuity, brought and adapted maize across the Americas—from the deserts of Arizona and Perú to the humid forests of Yucatán and Colombia, including up to the Mexican highlands, where maize was crossed with another wild teosinte plant—teosinte mexicana.

"Our results show that the mixture of maize with teosinte mexicana helped maize adapt to highland conditions and that this mixture is relevant in modern corn," Rellán-Álvarez said.

In the study, the researchers showed that genetic pieces from teosinte mexicana—namely the highlands version of HPC1—have been retained in modern-day maize.

"This retention—what scientists call introgression—is similar to modern-day humans retaining bits of Neanderthal in their genetic code. These pieces have been retained because they have been selected over time and bring some advantage," Rodríguez-Zapata said.

The study also showed the highlands variant of HPC1 in corn grown in Canada, the northern United States and northern Europe—which makes sense due to the colder climate found in those locations.

The NC State researchers are now examining the role of this and other genes involved in phosphorus metabolism to learn more sustainable ways of growing maize and perhaps to bring more teosinte mexicana into modern corn.

The paper appears in *Proceedings of the National Academy of Sciences*. Researchers from Penn State University, UC Davis, Iowa State University, Cornell University and Cold Spring Harbor co-authored the paper.

More information: Allison C. Barnes et al, An adaptive teosinte mexicana introgression modulates phosphatidylcholine levels and is associated with maize flowering time, *Proceedings of the National Academy of Sciences* (2022). DOI: 10.1073/pnas.2100036119

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