

[CASHIER:] That's three dollars for six.

[LOSIN:] OK

[CASHIER:] Alright, thank you.

[LOSIN:] Great, thank you so much. Have a great day.

[bag crumples]

[LOSIN:] This is an everyday scene, but it's actually pretty amazing. We've taken dozens of wild plants and transformed them into useful crops through the process of domestication. Humans have carefully bred these plants for generations to make them bigger, sweeter, more colorful. And it's hard to find a plant that we've transformed more completely than this one.

Maize.

Here in the U.S., most of us call it corn. And we eat a lot of it. There's corn bread, corn chips, corn cereal. If you look a little deeper, you'll find corn starch and corn syrup in hundreds of products. And a lot of the meat we eat comes from animals fed a corn-based diet. So, maize is all around us, but, for a long time, the origin of maize was a mystery. The ancestors of wheat pretty much look like wheat. The precursors of apples basically look like apples. But there's nothing in nature today that looks like this. This is the story of an unexpected collaboration, the story of geneticists and archaeologists working together to discover where maize really came from.

[LOSIN:] Christopher Columbus's crew were the first Europeans to see maize. But by the time Columbus arrived, people all over the Americas had been growing maize for thousands of years. Archeological evidence from around the world reveals that, starting around 10,000 years ago, humans were beginning to live in larger settlements and manipulate wild plant and animal species to better suit their needs. In the case of plants, this process of domestication led to plants that we call crops—like wheat, apples, and potatoes. And in most cases, the wild relatives of these crops can still be found in nature. But you can't find anything that looks like maize growing in the wild today. And even the earliest fossil ears of maize, which are more than 6,000 years old, already look essentially like today's crop.

So where did maize come from? Many scientists thought that the ancestor of maize must be extinct. But a brilliant young geneticist discovered something that made him think that the ancestor of maize was right in front of us. His name was George Beadle. Beadle was studying a grass from Central America called teosinte. He found that teosinte's chromosomes looked nearly identical to those of maize. He also showed that teosinte and maize could produce fertile hybrid offspring, meaning that they must be closely related. Beadle concluded that teosinte was likely the ancestor of maize.

But many botanists doubted the young scientist's claims. Maize expert Dr. John Doebley, at the University of Wisconsin, told me why.

[DOEBLEY:] So Neil, the reason I wanted to bring you out here was to show you just how different corn and teosinte are.

[LOSIN:] Yeah.

[DOEBLEY:] This is a teosinte plant, and it doesn't look anything like a typical corn plant.

[LOSIN:] No.

[DOEBLEY:] You can start by just looking at the base, it just branches a lot. So, it is a very bushy creature, and quite different from a corn plant, such as you see here ...

[LOSIN:] Yeah.

[DOEBLEY:] ... where there's just a single main stalk, no branches, except for these two short branches, each of which has an ear on it.

[LOSIN:] The dramatic difference in branching between teosinte and maize is just the beginning. When you look at an ear of corn, you can see hundreds of kernels exposed on the cob. But teosinte is different. Each ear only has a handful of kernels, each enclosed in a fruit case that's so hard, you might crack a tooth if you tried to eat it. It was no wonder that botanists doubted that teosinte could be the ancestor of maize. Beadle moved on to other questions in genetics, which ultimately earned him the Nobel Prize. But the origin of maize continued to intrigue him. And after his retirement, he returned to that question.

To silence the skeptics, Beadle had to show how humans could have transformed this into this. So, after his retirement, he launched one of the biggest breeding experiments in history to settle that question once and for all. For Beadle, the key question was "How many genes control the differences between maize and teosinte?" If that number were small, then it wouldn't have been too hard for early humans to transform teosinte into maize.

He began by cross-breeding maize with teosinte. In most plants and animals, individuals inherit two copies of each gene: one from each parent. So, the offspring from this first-generation cross between teosinte and maize—the F1 generation—would have one copy of each gene from teosinte and one from maize. These F1 plants would then be crossed with one another to produce the F2 generation.

This is where things get interesting. If only one gene differs between teosinte and maize, then one in four of the F2 plants should look just like maize, and one in four ought to look like teosinte. If two genes are at work, this number drops to one in sixteen. For three genes, it's one in sixty-four, and so on. If more than three genes were involved, Beadle was going to need a lot of plants. He decided to grow 50,000 F2 plants for his experiment.

And what did he find? About one in 500 plants looked identical to teosinte, and a similar number looked just like maize. That number suggested that changes in just four or five genes were responsible

for all the major differences between the two plants. So, George Beadle was right! The real ancestor of maize was teosinte, and it was right in front of us all along.

But many varieties of teosinte grow throughout Mexico and Central America, and humans have lived there for thousands of years. So, where and when did they first transform teosinte into maize? Doebley's team set out to find the answer. They collected DNA samples from different teosinte varieties throughout Mexico to compare their DNA sequences to those of modern maize. The more closely related two groups of organisms are, the more similar their DNA sequences will be. Doebley's team looked for the teosinte variety with DNA sequences most similar to maize.

[DOEBLEY:] We've actually figured out that all of modern corn traces back to one type of teosinte, in the southwestern part of Mexico, near a river called the Balsas River.

[LOSIN:] The relatively small number of DNA sequence differences between maize and the Balsas River teosinte yielded another critical piece of information.

[DOEBLEY:] We can take teosinte and corn and ask how many mutations do they differ by, and then knowing the rate at which mutations occur, make a prediction about how long ago their paths separated.

[LOSIN:] The more differences in the DNA of two groups of organisms, the longer it's been since their ancestors were all one species.

[DOEBLEY:] Our estimate is that the original domestication of corn would've taken place sometime around 9,000 years ago.

[LOSIN:] Based on genetics, Doebley's team had come up with a hypothesis about where and when maize was domesticated. But the ultimate test would require independent evidence, from outside the field of genetics. I visited Dr. Dolores Piperno at the Smithsonian Tropical Research Institute in Panama to see that evidence.

[PIPERNO:] Hi, Neil. How do you do? Welcome to Panama.

[LOSIN:] So you're an archaeologist. What did you think when this geneticist from Wisconsin, analyzing DNA, said, "Here's where we need to look for the earliest evidence of maize domestication?"

[PIPERNO:] Teosinte is distributed all over Mexico—highlands, lowlands, it gets into Nicaragua. So the question for archeologists was, where do we go? And Dr. Doebley's work told us exactly where to go.

[LOSIN:] Nine thousand years ago, people living in this area were taking shelter and preparing food in caves and rock shelters.

[PIPERNO:] When we went to the central Balsas Valley, one of the things we did was to ask the local people, "Do you know of any caves or big rock shelters?" And that's how we found the Xihuatotla shelter.

[LOSIN:] So people took shelter there, they slept there, they probably ate there.

[PIPERNO:] They ate there, they cooked their food there.

[LOSIN:] But finding evidence of ancient maize wouldn't be easy. In the tropical environment of ancient Mexico, the cobs and kernels would typically be scavenged or decompose. But Dr. Piperno wasn't looking for such obvious evidence.

[PIPERNO:] These were the earliest plant-processing tools, ... we call them plant grinding stones—that's what they were used for—and these were no more than river cobbles.

[LOSIN:] Dr. Piperno showed me how ancient people used these stone tools to grind up maize and other crops. In the process, tiny plant pieces might be deposited on the tools' surface, leaving behind "microfossils."

[PIPERNO:] We found hundreds of these microfossils right on the grind surface of the stone, and like the seeds, they're very highly diagnostic.

[LOSIN:] So even with these microscopic traces, you can tell the difference between corn and teosinte?

[PIPERNO:] Yes, we can tell the difference.

[LOSIN:] Finding maize microfossils on the grinding tools meant that the humans living in the Xihuatoxtla shelter were processing maize for food. But how long ago? Archaeologists can calculate the age of ancient remains using radiocarbon dating. But microfossils are too small to date using this method. So, Dr. Piperno used charcoal found in the same sediment layer as the grinding stones to determine the age of the microfossils.

[LOSIN:] And so what was the oldest date of these maize remains?

[PIPERNO:] The ... it's very interesting how well the genetic and archaeological data fit together. The oldest charcoal date we received back was about 8,700 years ago.

[LOSIN:] That date coincided almost perfectly with the date Dr. Doebley predicted from the genetic evidence. So nearly 9,000 years ago, humans had already produced an early version of maize. But how was teosinte transformed into maize? Back in Dr. Doebley's lab in Wisconsin, I learned about the genetic changes involved.

[LOSIN:] One of the main differences between teosinte and maize is that the teosinte seeds are encased in this really hard fruitcase that makes it really difficult to eat. So clearly that's something that had to change.

[DOEBLEY:] That's right. And the remarkable thing is that having a fruitcase versus not having a fruitcase is basically controlled by a single gene.

[LOSIN:] A single gene?

[DOEBLEY:] A single gene.

[LOSIN:] To test this gene's function, Dr. Doebley's team did a clever experiment. They carefully crossbred maize and teosinte to introduce the maize version of the fruitcase gene into teosinte plants. When they did that, the teosinte kernels, which are normally enclosed in a hard fruitcase, become partially exposed, almost like little corn kernels. When they did the opposite—putting the teosinte fruitcase gene into maize plants—the fruitcase became larger and started to cover up the maize kernels, similar to teosinte.

[DOEBLEY:] One gene makes a pretty dramatic change.

[LOSIN:] So, another really obvious difference between teosinte and corn is that teosinte produces dozens of these little tiny ears on a plant that branches a lot, and corn just produces a couple of ears on a plant that hardly branches at all. So what's going on there?

[DOEBLEY:] There is one gene that we've identified that plays a central role in that process. And you call it the branching gene.

[LOSIN:] Dr. Doebley explained how putting the teosinte version of the branching gene into maize made the maize plants more branched, like teosinte. And putting the maize version of the gene into teosinte made the teosinte plants less branched. Dr. Doebley has shown that the fruitcase gene, the branching gene, and just a few others—a small number of genes, just as George Beadle predicted—were responsible for setting in motion all the major differences between maize and teosinte. But how could so few genes cause such huge changes? Why were these genes so powerful?

[DOEBLEY:] They both belong to a, a special class of genes called regulatory genes. And these are genes that directly regulate the activities of other genes.

[LOSIN:] And so, when we move the teosinte version of one of these genes into a corn plant, or vice versa, we're actually changing more than just that one gene?

[DOEBLEY:] That's right, they can turn other genes on and off. You could think of these genes as something like the conductor of an orchestra. And if you would take the conductor from one orchestra and give that orchestra, say, a new conductor ...

[LOSIN:] Just like we did moving some genes from teosinte to maize or vice versa.

[DOEBLEY:] Right. And you could get a very different quality of music, even though all of the musicians and all of the instruments remain the same.

[LOSIN:] These regulatory genes probably influence the activity of hundreds of other genes, which explains how mutations in just a few regulatory genes could dramatically transform teosinte. But there was still one thing I couldn't figure out. So, I understand now how teosinte was transformed into maize, but the thing that's still bothering me is that, teosinte really doesn't seem like a very good crop. So, why would anyone have started growing it in the first place?

[DOEBLEY:] Well, George Beadle actually had an idea about that question. And his idea was that they might have used it like popcorn.

[LOSIN:] Huh.

[DOEBLEY:] And Beadle did an experiment to test his hypothesis that they used it like popcorn, and we can do that same experiment here today.

[LOSIN:] Alright, let's do it. Remember, the nutritious kernels of teosinte are trapped inside hard fruitcases. But if they popped, like maize kernels, that could be one way the earliest farmers could have eaten teosinte. In Dr. Doebley's lab, we were about to find out whether the ancestor of maize could pop.

[DOEBLEY:] Oh, there goes one. Ooh, that was a good one!

[LOSIN:] Ok, so we actually, we've got some popped teosinte here, and uh, I'm gonna, I'm gonna actually give this a try.

[DOEBLEY:] Looks good to me.

[LOSIN:] And that's basically just like popcorn. That's pretty cool.

[DOEBLEY:] Tastes like popcorn.

[LOSIN:] The archeological and genetic evidence tell us a remarkable story. About 9,000 years ago, people living in the Balsas River region of Mexico began cultivating an unassuming grass called teosinte and ended up transforming it into the amazing crop we now call maize.