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PART I
THE EDIBLE FOUNDATIONS OF CIVILIZATION

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THE INVENTION OF FARMING

I have seen great surprise expressed in horticultural works at the wonderful skill of gardeners, in having produced such splendid results from such poor materials; but the art has been simple, and as far as the final result is concerned, has been followed almost unconsciously. It has consisted in always cultivating the best-known variety, sowing its seeds, and, when a slightly better variety chanced to appear, selecting it, and so onwards.

— CHARLES DARWIN, *The Origin of Species*

FOODS AS TECHNOLOGIES

What embodies the bounty of nature better than an ear of corn? With a twist of the wrist it is easily plucked from the stalk with no waste or fuss. It is packed with tasty, nutritious kernels that are larger and more numerous than those of other cereals. And it is surrounded by a leafy husk that shields

Standage, Tom, "Invention of Farming", Ch01, pp19-40. The Edible History of Humanity. Waterville, Me.: Thorndike Press, 2009.

it from pests and moisture. Maize appears to be a gift from nature; it even comes wrapped up. But appearances can be deceptive. A cultivated field of maize, or any other crop, is as man-made as a microchip, a magazine, or a missile. Much as we like to think of farming as natural, ten thousand years ago it was a new and alien development. Stone Age hunter-gatherers would have regarded neatly cultivated fields, stretching to the horizon, as a bizarre and unfamiliar sight. Farmed land is as much a technological landscape as a biological one. And in the grand scheme of human existence, the technologies in question — domesticated crops — are very recent inventions.

The ancestors of modern humans diverged from apes about four and a half million years ago, and "anatomically modern" humans emerged around 150,000 years ago. All of these early humans were hunter-gatherers who subsisted on plants and animals that were gathered and hunted in the wild. It is only within the past 11,000 years or so that humans began to cultivate food deliberately. Farming emerged independently in several different times and places, and had taken hold in the Near East by around 8500 B.C., in China by around

7500 B.C., and in Central and South America by around 3500 B.C. From these three main starting points, the technology of farming then spread throughout the world to become mankind's chief means of food production.

This was a remarkable change for a species that had relied on a nomadic lifestyle based on hunting and gathering for its entire previous existence. If the 150,000 years since modern humans emerged are likened to one hour, it is only in the last four and a half minutes that humans began to adopt farming, and agriculture only became the dominant means of providing human subsistence in the last minute and a half. Humanity's switch from foraging to farming, from a natural to a technological means of food production, was recent and sudden.

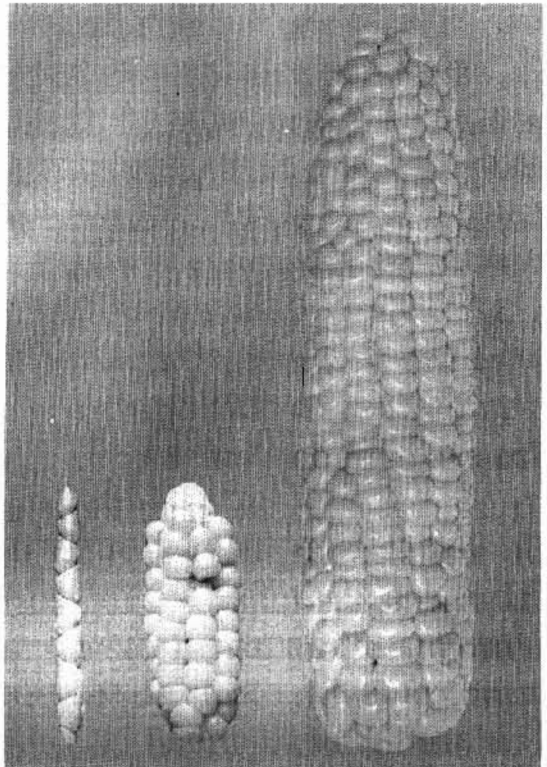
Though many animals gather and store seeds and other foodstuffs, humans are unique in deliberately cultivating specific crops and selecting and propagating particular desired characteristics. Like a weaver, a carpenter, or a blacksmith, a farmer creates useful things that do not occur in nature. This is done using plants and animals that have been modified, or domesticated, so that they better suit human purposes. They are human creations, carefully crafted tools that are used to produce food in novel forms, and in far greater quantities than would occur naturally. The significance of their development cannot be overstated, for they literally made possible the modern world. Three domesticated plants in particular — wheat, rice, and maize — proved to be most significant. They laid the foundations for civilization and continue to underpin human society to this day.

The Man-Made Nature of Maize

Maize, more commonly known as corn in America, provides the best illustration that domesticated crops are unquestionably human creations. The distinction between wild and domesticated plants is not a hard and fast one. Instead, plants occupy a continuum: from entirely wild plants, to domesticated ones that have had some characteristics modified to suit humans, to entirely domesticated plants, which can only reproduce with human assistance. Maize falls into the last of these categories. It is the result of human propagation of a series of random genetic mutations that transformed it from a simple grass into a bizarre, gigantic mutant that can no longer survive in the wild. Maize is descended from teosinte, a

wild grass indigenous to modern-day Mexico. The two plants look very different. But just a few genetic mutations, it turns out, were sufficient to transform one into the other.

One obvious difference between teosinte and maize is that teosinte ears consist of two rows of kernels surrounded by tough casings, or glumes, which protect the edible kernels within. A single gene, called *tga1* by modern geneticists, controls the size of these glumes, and a mutation in the gene results in exposed kernels. This means the kernels are less likely to survive the journey through the digestive tract of an animal, placing mutant plants at a reproductive disadvantage to nonmutants, at least in the normal scheme of things. But the exposed kernels would also have made teosinte far more attractive to human foragers, since there would have been no need to remove the glumes before consumption. By gathering just the mutant plants with exposed kernels, and then sowing some of them as seeds, proto-farmers could increase the proportion of plants with exposed kernels. The *tga1* mutation, in short, made teosinte plants less likely to survive in the wild, but also made them more attractive to humans, who propagated the mutation. (The glumes



Progression from teosinte to proto-maize and modern maize.

in maize are so reduced that you only notice them today when they get stuck between your teeth. They are the silky, transparent film that surrounds each kernel.)

Another obvious difference between teosinte and maize lies in the overall structure, or architecture, of the two plants, which determines the position and number of the male and female reproductive parts, or inflorescences. Teosinte has a highly branched

architecture with multiple stalks, each of which has one male inflorescence (the tassel) and several female inflorescences (the ears). Maize, however, has a single stalk with no branches, a single tassel at the top, and far fewer but much larger ears halfway up the stalk, enclosed in a leafy husk. Usually there is just one ear, but in some varieties of maize there can be two or three. This change in architecture seems to be the result of a mutation in a gene known as *tb1*. From the plant's point of view, this mutation is a bad thing: It makes fertilization, in which pollen from the tassel must make its way down to the ear, more difficult. But from the point of view of humans, it is a very helpful mutation, since a small number of large ears is easier to collect than a large number of small ones. Accordingly, proto-farmers would have been more likely to gather ears from plants with this mutation. By sowing their kernels as seeds, humans propagated another mutation that resulted in an inferior plant, but a superior food.

The ears, being closer to the ground, end up closer to the nutrient supply and can potentially grow much larger. Once again, human selection guided this process. As proto-farmers gathered ears of proto-maize, they would have given preference to plants with larger ears; and kernels from those ears would then have been used as seeds. In this way, mutations that resulted in larger ears with more kernels were propagated, so that the ears grew larger from one generation to the next and became corn cobs. This can clearly be seen in the archaeological record: At one cave in Mexico, a sequence of cobs has been found, increasing in length from a half inch to eight inches long. Again, the very trait that made maize attractive to humans made it less viable in the wild. A plant with a large ear cannot propagate itself from one year to the next, because when the ear falls to the ground and the kernels sprout, the close proximity of so many kernels competing for the nutrients in the soil prevents any of them from growing. For the plant to grow, the kernels must be manually separated from the cob and planted a sufficient distance apart — something only humans can do. As maize ears grew larger, in short, the plant ended up being entirely dependent on humans for its continued existence.

What started off as an unwitting process of selection eventually became deliberate, as early farmers began to propagate desirable traits on purpose. By transferring pollen from the tassel of one plant to the silks of

another, it was possible to create new varieties that combined the attributes of their parents. These new varieties had to be kept away from other varieties to prevent the loss of desirable traits. Genetic analysis suggests that one particular type of teosinte, called Balsas teosinte, is most likely to have been the progenitor of maize. Further analysis of regional varieties of Balsas teosinte suggests that maize was originally domesticated in central Mexico, where the modern-day states of Guerrero, México, and Michoacán meet. From here, maize spread and became a staple food for peoples throughout the Americas: the Aztecs and Maya of Mexico, the Incas of Peru, and many other tribes and cultures throughout North, South, and Central America.

But maize could only become a dietary mainstay with the help of a further technological twist, since it is deficient in the amino acids lysine and tryptophan, and the vitamin niacin, which are essential elements of a healthy human diet. When maize was merely one foodstuff among many these deficiencies did not matter, since other foods, such as beans and squash, made up for them. But a maize-heavy diet results in pellagra, a nutritional disease characterized by nausea, rough skin, sensitivity to light, and dementia. (Light sensitivity due to pellagra is thought to account for the origin of European vampire myths, following the introduction of maize into European diets in the eighteenth century.) Fortunately, maize can be rendered safe by treating it with calcium hydroxide, in the form of ash from burnt wood or crushed shells, which is either added directly to the cooking pot, or mixed with water to create an alkaline solution in which the maize is left to soak overnight. This has the effect of softening the kernels and making them easier to prepare, which probably explains the origin of the practice. More importantly but less visibly, it also liberates amino acids and niacin, which exist in maize in an inaccessible or "bound" form called niacytin. The resulting processed kernels were called *nixtamal* by the Aztecs, so that the process is known today as nixtamalization. This practice seems to have been developed as early as 1500 B.C.; without it, the great maize-based cultures of the Americas could never have been established.

All of this demonstrates that maize is not a naturally occurring food at all. Its development has been described by one modern scientist as the most impressive feat of domestication and genetic modification ever

undertaken. It is a complex technology, developed by humans over successive generations to the point where maize was ultimately incapable of surviving on its own in the wild, but could deliver enough food to sustain entire civilizations.

Cereal Innovation

Maize is merely one of the most extreme examples. The world's two other major staples, which went on to underpin civilization in the Near East and Asia respectively, are wheat and rice. They too are the results of human selective processes that propagated desirable mutations to create more convenient and abundant foodstuffs. Like maize, both wheat and rice are cereal grains, and the key difference between their wild and domesticated forms is that domesticated varieties are "shatterproof." The grains are attached to a central axis known as the rachis. As the wild grains ripen the rachis becomes brittle, so that when touched or blown by the wind it shatters, scattering the grains as seeds. This makes sense from the plant's perspective, since it ensures that the grains are only dispersed once they have ripened. But it is very inconvenient from the point of view of humans who wish to gather them.

In a small proportion of plants, however, a single genetic mutation means the rachis does not become brittle, even when the seeds ripen. This is called a "tough rachis." This mutation is undesirable for the plants in question, since they are unable to disperse their seeds. But it is very helpful for humans gathering wild grains, who are likely to gather a disproportionate number of tough-rachis mutants as a result. If some of the grains are then planted to produce a crop the following year, the tough-rachis mutation will be propagated, and every year the proportion of tough-rachis mutants will increase. Archaeologists have demonstrated in field experiments with wheat that this is exactly what happens. They estimate that plants with tough, shatterproof rachises would become predominant within about two hundred years — which is roughly how long the domestication of wheat seems to have taken, according to the archaeological record. (In maize, the cob is in fact a gigantic shatterproof rachis.)

As with maize, proto-farmers selected for other desirable characteristics in wheat, rice, and other cereals during the process of domestication. A mutation in wheat causes the hard glumes that cover each grain to separate more easily, resulting in "self-

threshing" varieties. The individual grains are less well protected as a result, so this mutation is bad news in the wild. But it is helpful to human farmers, since it makes it easier to separate the edible grains after beating sheaves of cut wheat on a stone threshing floor. When grains were being plucked from the floor, small grains and those with glumes still attached would have been passed over in favor of larger ones without glumes. This helped to propagate these helpful mutations.

Another trait common to many domesticated crops is the loss of seed dormancy, the natural timing mechanism that determines when a seed germinates. Many seeds require specific stimuli, such as cold or light, before they will start growing, to ensure that they only germinate under favorable circumstances. Seeds that remain dormant until after a cold spell, for example, will not germinate in the autumn, but will wait until after the winter has passed. Human farmers would often like seeds to start growing as soon as they are planted, however. Given a collection of seeds, some of which exhibit seed dormancy and some of which do not, it is clear that those that start growing right away stand a better chance of being gathered and thus forming the basis of the next crop. So any mutations that suppress seed dormancy will tend to be propagated.

Similarly, wild cereals germinate and ripen at different times. This ensures that whatever the pattern of rainfall, at least some of the grains will mature to provide seeds for the following year. Harvesting an entire field of grain on the same day, however, favors grains that are almost ripe at the time. Grains that are over-ripe or under-ripe will be less viable if sown as seeds the following year. The effect is to reduce the variation in ripening time from one year to the next, so that eventually the entire field ripens at the same time. This is bad from the plant's point of view, since it means the entire crop can potentially fail. But it is far more convenient for human farmers.

In the case of rice, human intervention helped to propagate desirable properties such as taller and larger plants to aid harvesting, and more secondary branches and larger grains to increase yield. But domestication also made wheat and rice more dependent on human intervention. Rice lost its natural ability to survive in flood waters, for example, as it was pampered by human farmers. And both wheat and rice were less able to reproduce by

themselves because of the human-selected shatterproof rachis. The domestication of wheat, rice, and maize, the three main cereal grains, and of their lesser siblings barley, rye, oats, and millet, were all variations on the same familiar genetic theme: more convenient food, less resilient plant.

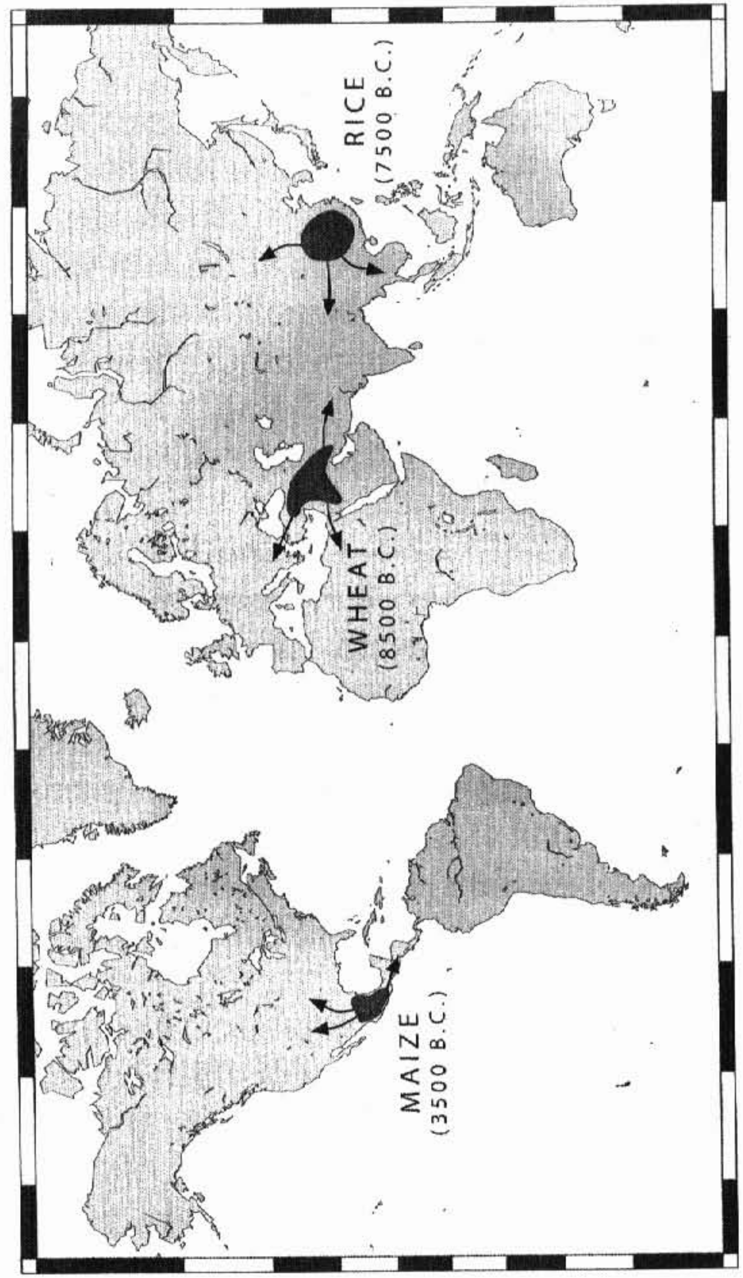
The same trade-off occurred as humans domesticated animals for the purpose of providing food, starting with sheep and goats in the Near East around 8000 B.C. and followed by cattle and pigs soon afterward. (Pigs were independently domesticated in China at roughly the same time, and the chicken was domesticated in southeast Asia around 6000 B.C.) Most domesticated animals have smaller brains and less acute eyesight and hearing than their wild ancestors. This reduces their ability to survive in the wild but makes them more docile, which suits human farmers.

Humans became dependent on their new creations, and vice versa. By providing a more dependable and plentiful food supply, farming provided the basis for new lifestyles and far more complex societies. These cultures relied on a range of foods, but the most important were the cereals: wheat and barley in the Near East, rice and millet in Asia, and maize in the Americas. The civilizations that subsequently arose on these edible foundations, including our own, owe their existence to these ancient products of genetic engineering.

PRESENT AT THE CREATION

This debt is acknowledged in many myths and legends in which the creation of the world, and the emergence of civilization after a long period of barbarism, are closely bound up with these vital crops. The Aztecs of Mexico, for example, believed men were created five times, each generation being an improvement over the last. Teosinte was said to have been man's principal food in the third and fourth creations. Finally, in the fifth creation, man nourished himself with maize. Only then did he prosper, and his descendants populated the world.

The creation story of the Maya of southern Mexico, recounted in the Popul Vuh (or "sacred book"), also involves repeated attempts to create mankind. At first the gods fashioned men out of mud, but the resulting creatures could barely see, could not move at all, and were soon washed away. So the gods tried again, this time making men out of wood. These creatures could walk on all fours and speak, but they lacked blood and souls, and they failed to honor the gods.



The centers of origin for domesticated maize, wheat, and rice.

The gods destroyed these men, too, so that all that remained of them were a few tree-dwelling monkeys. Finally, after much discussion about the appropriate choice of ingredients, the gods made a third generation of men from white and yellow ears of maize: "Of yellow maize and of white maize they made their flesh; of corn-meal dough they made the arms and the legs of man. Only dough of corn-meal went into the flesh of our first fathers, the four men, who were created." The Maya believed they were descended from these four men and their wives, who were created shortly afterward.

Maize also features in the story told by the Incas of South America to explain their origins. In ancient times, it is said, the people around Lake Titicaca lived like wild animals. The sun god, Inti, took pity on them and sent his son Manco Capac and his daughter Mama Ocllo, who were also husband and wife, to civilize them. Inti gave Manco Capac a golden stick with which to test the fertility of the soil and its suitability for growing maize. Having found a suitable place, they were to found a state and instruct its people in the proper worship of the sun god. The couple's travels finally brought them to the Cuzco Valley, where the golden stick disappeared into the

ground. Manco Capac taught the people about farming and irrigation, Mama Ocllo taught them about spinning and weaving, and the valley became the center of the Inca civilization. Maize was regarded as a sacred crop by the Incas, even though potatoes also formed a large part of their diet.

Rice too appears in countless myths in the countries where it is grown. In Chinese myths, rice appears to save mankind when it is on the verge of starvation. According to one story, the goddess Guan Yin took pity on the starving humans and squeezed her breasts to produce milk, which flowed into the previously empty ears of the rice plants to become rice grains. She then pressed harder, causing a mixture of blood and milk to flow into some of the plants. This is said to explain why rice exists in both red and white varieties. Another Chinese tale tells of a great flood, after which very few animals remained for hunting. As they searched for food, the people saw a dog coming toward them with bunches of long, yellow seeds hanging from its tail. They planted the seeds, which grew into rice and dispelled their hunger forever. In a different series of rice myths, told in Indonesia and throughout the islands of Indochina, rice appears as a delicate and virtuous maiden. The Indonesian rice goddess, Sri, is the goddess of the earth who protects the people against hunger. One story tells how Sri was killed by the other gods to protect her from the lecherous advances of the king of the gods, Batara Guru. When her body was buried, rice sprouted from her eyes and sticky rice grew from her chest. Filled with remorse, Batara Guru gave these crops to mankind to cultivate.

The tale of the creation of the world and the emergence of civilization told by the Sumerians, the ancient inhabitants of what is now southern Iraq, refers to a time after the creation of the world by Anu, when people existed but agriculture was unknown. Ashnan, the grain goddess, and Lahar, the goddess of sheep, had not yet appeared; Tagtug, patron of the craftsmen, had not been born; and Mirsu, the god of irrigation, and Sumugan, the god of cattle, had not arrived to help mankind. As a result, "the grain . . . and barley-grain for the cherished multitudes were not yet known." Instead, the people ate grass and drank water. The goddesses of grain and flocks were then created to provide food for the gods, but no matter how much the gods ate, they were not filled. Only with the emergence of civilized men, who made

regular offerings of food to the gods, were the gods' appetites finally satisfied. So domesticated crops and animals were a gift to man that conferred upon him an obligation to make regular food offerings to the gods. This tale preserves a folk memory of a time before the adoption of farming, when humans were still foragers. Similarly, a Sumerian hymn to the grain goddess describes a barbaric age before cities, fields, sheepfolds, and cattle stalls — an era that came to an end when the grain goddess inaugurated a new era of civilization.

Contemporary explanations of the genetic basis of plant and animal domestication are really just the modern, scientific version of these ancient and strikingly similar creation myths from around the world. Today, we would say that the abandonment of hunting and gathering, the domestication of plants and animals, and the adoption of a settled lifestyle based on farming put mankind on the road to the modern world, and that those earliest farmers were the first modern, "civilized" humans. Admittedly, this is a rather less colorful account than those provided by the various creation myths. But given that the domestication of certain key cereal crops was an essential step toward the emergence of civilization, there is no doubt that these ancient tales contain far more than just a grain of truth.