GUNS, GERMS, AND STEEL

THE FATES OF HUMAN SOCIETIES

Jared Diamond

W. W. Norton & Company
New York London

CHAPTER 4

FARMER POWER

As a teenager, I spent the summer of 1956 in Montana, working for an elderly farmer named Fred Hirschy. Born in Switzerland, Fred had come to southwestern Montana as a teenager in the 1890s and proceeded to develop one of the first farms in the area. At the time of his arrival, much of the original Native American population of hunter-gatherers was still living there.

My fellow farmhands were, for the most part, tough whites whose normal speech featured strings of curses, and who spent their weekdays working so that they could devote their weekends to squandering their week's wages in the local saloon. Among the farmhands, though, was a member of the Blackfoot Indian tribe named Levi, who behaved very differently from the coarse miners—being polite, gentle, responsible, sober, and well spoken. He was the first Indian with whom I had spent much time, and I came to admire him.

It was therefore a shocking disappointment to me when, one Sunday morning, Levi too staggered in drunk and cursing after a Saturday-night binge. Among his curses, one has stood out in my memory: "Damn you, Fred Hirschy, and damn the ship that brought you from Switzerland!" It poignantly brought home to me the Indians' perspective on what I, like other white schoolchildren, had been taught to view as the heroic conquest of the American West. Fred Hirschy's family was proud of him, as a pioneer farmer who had succeeded under difficult conditions. But Levi's tribe of hunters and famous warriors had been robbed of its lands by the immigrant white farmers. How did the farmers win out over the famous warriors?

For most of the time since the ancestors of modern humans diverged from the ancestors of the living great apes, around 7 million years ago, all humans on Earth fed themselves exclusively by hunting wild animals and gathering wild plants, as the Blackfeet still did in the 19th century. It was only within the last 11,000 years that some peoples turned to what is termed food production: that is, domesticating wild animals and plants and eating the resulting livestock and crops. Today, most people on Earth consume food that they produced themselves or that someone else produced for them. At current rates of change, within the next decade the few remaining bands of hunter-gatherers will abandon their ways, disintegrate, or die out, thereby ending our millions of years of commitment to the hunter-gatherer lifestyle.

Different peoples acquired food production at different times in prehistory. Some, such as Aboriginal Australians, never acquired it at all. Of those who did, some (for example, the ancient Chinese) developed it independently by themselves, while others (including ancient Egyptians) acquired it from neighbors. But, as we'll see, food production was indirectly a prerequisite for the development of guns, germs, and steel. Hence geographic variation in whether, or when, the peoples of different continents became farmers and herders explains to a large extent their subsequent contrasting fates. Before we devote the next six chapters to understanding how geographic differences in food production arose, this chapter will trace the main connections through which food production led to all the advantages that enabled Pizarro to capture Atahuallpa, and Fred Hirschy's people to dispossess Levi's (Figure 4.1).

The first connection is the most direct one: availability of more consum-

Factors Underlying the Broadest Pattern of History

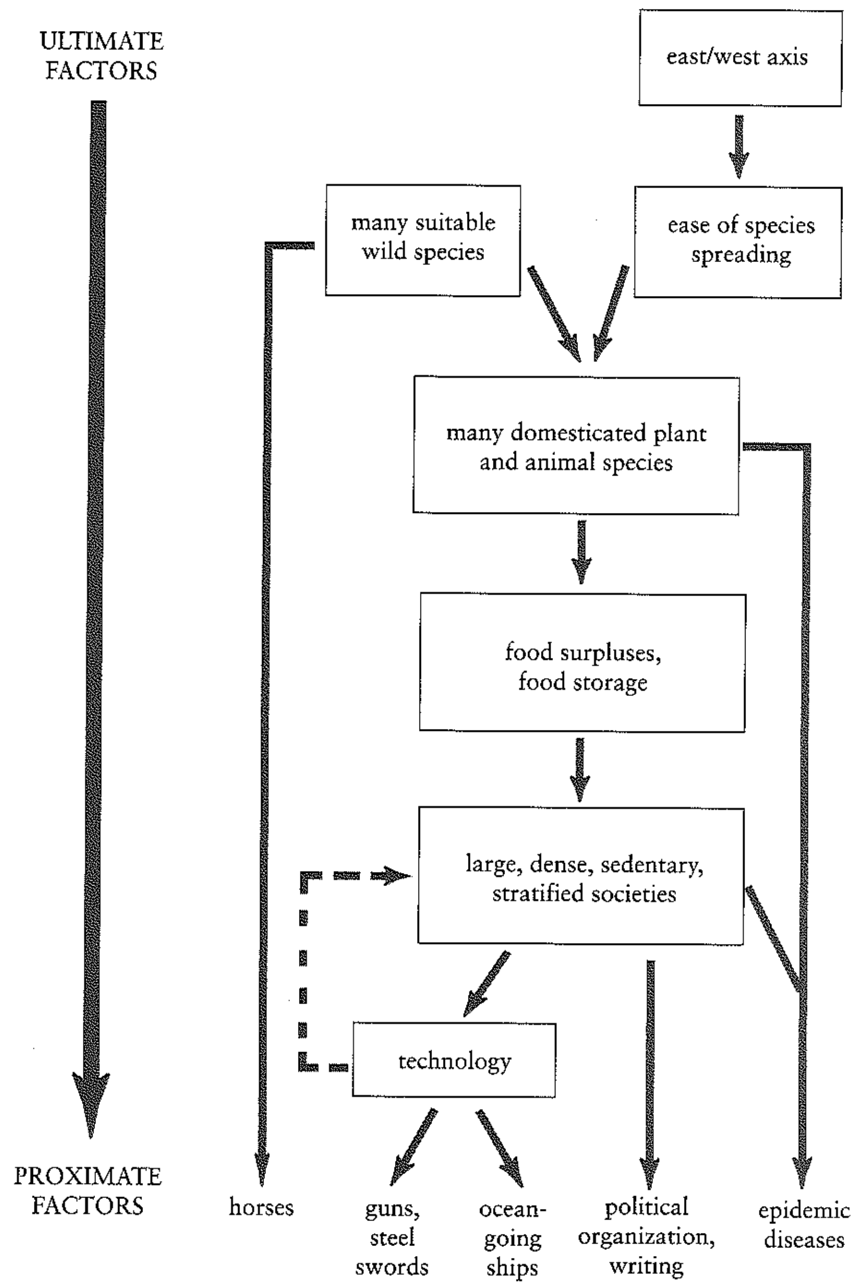

Figure 4.1. Schematic overview of the chains of causation leading up to proximate factors (such as guns, horses, and diseases) enabling some peoples to conquer other peoples, from ultimate factors (such as the orientation of continental axes). For example, diverse epidemic diseases of humans evolved in areas with many wild plant and animal species suitable for domestication, partly because the resulting crops and livestock helped feed dense societies in which epidemics could maintain themselves, and partly because the diseases evolved from germs of the domestic animals themselves.

able calories means more people. Among wild plant and animal species, only a small minority are edible to humans or worth hunting or gathering. Most species are useless to us as food, for one or more of the following reasons: they are indigestible (like bark), poisonous (monarch butterflies and death-cap mushrooms), low in nutritional value (jellyfish), tedious to prepare (very small nuts), difficult to gather (larvae of most insects), or dangerous to hunt (rhinoceroses). Most biomass (living biological matter) on land is in the form of wood and leaves, most of which we cannot digest.

By selecting and growing those few species of plants and animals that we can eat, so that they constitute 90 percent rather than 0.1 percent of the biomass on an acre of land, we obtain far more edible calories per acre. As a result, one acre can feed many more herders and farmers—typically, 10 to 100 times more—than hunter-gatherers. That strength of brute numbers was the first of many military advantages that food-producing tribes gained over hunter-gatherer tribes.

In human societies possessing domestic animals, livestock fed more people in four distinct ways: by furnishing meat, milk, and fertilizer and by pulling plows. First and most directly, domestic animals became the societies' major source of animal protein, replacing wild game. Today, for instance, Americans tend to get most of their animal protein from cows, pigs, sheep, and chickens, with game such as venison just a rare delicacy. In addition, some big domestic mammals served as sources of milk and of milk products such as butter, cheese, and yogurt. Milked mammals include the cow, sheep, goat, horse, reindeer, water buffalo, yak, and Arabian and Bactrian camels. Those mammals thereby yield several times more calories over their lifetime than if they were just slaughtered and consumed as meat.

Big domestic mammals also interacted with domestic plants in two ways to increase crop production. First, as any modern gardener or farmer still knows by experience, crop yields can be greatly increased by manure applied as fertilizer. Even with the modern availability of synthetic fertilizers produced by chemical factories, the major source of crop fertilizer today in most societies is still animal manure—especially of cows, but also of yaks and sheep. Manure has been valuable, too, as a source of fuel for fires in traditional societies.

In addition, the largest domestic mammals interacted with domestic plants to increase food production by pulling plows and thereby making it possible for people to till land that had previously been uneconomical for farming. Those plow animals were the cow, horse, water buffalo, Bali cattle, and yak / cow hybrids. Here is one example of their value: the first prehistoric farmers of central Europe, the so-called Linearbandkeramik culture that arose slightly before 5000 B.C., were initially confined to soils light enough to be tilled by means of hand-held digging sticks. Only over a thousand years later, with the introduction of the ox-drawn plow, were those farmers able to extend cultivation to a much wider range of heavy soils and tough sods. Similarly, Native American farmers of the North American Great Plains grew crops in the river valleys, but farming of the tough sods on the extensive uplands had to await 19th-century Europeans and their animal-drawn plows.

All those are direct ways in which plant and animal domestication led to denser human populations by yielding more food than did the hunter-gatherer lifestyle. A more indirect way involved the consequences of the sedentary lifestyle enforced by food production. People of many hunter-gatherer societies move frequently in search of wild foods, but farmers must remain near their fields and orchards. The resulting fixed abode contributes to denser human populations by permitting a shortened birth interval. A hunter-gatherer mother who is shifting camp can carry only one child, along with her few possessions. She cannot afford to bear her next child until the previous toddler can walk fast enough to keep up with the tribe and not hold it back. In practice, nomadic hunter-gatherers space their children about four years apart by means of lactational amenorrhea, sexual abstinence, infanticide, and abortion. By contrast, sedentary people, unconstrained by problems of carrying young children on treks, can bear and raise as many children as they can feed. The birth interval for many farm peoples is around two years, half that of hunter-gatherers. That higher birthrate of food producers, together with their ability to feed more people per acre, lets them achieve much higher population densities than hunter-gatherers.

A separate consequence of a settled existence is that it permits one to store food surpluses, since storage would be pointless if one didn't remain nearby to guard the stored food. While some nomadic hunter-gatherers may occasionally bag more food than they can consume in a few days, such a bonanza is of little use to them because they cannot protect it. But stored food is essential for feeding non-food-producing specialists, and certainly for supporting whole towns of them. Hence nomadic hunter-gatherer societies have few or no such full-time specialists, who instead first appear in sedentary societies.

Two types of such specialists are kings and bureaucrats. Hunter-gatherer societies tend to be relatively egalitarian, to lack full-time bureaucrats and hereditary chiefs, and to have small-scale political organization at the level of the band or tribe. That's because all able-bodied hunter-gatherers are obliged to devote much of their time to acquiring food. In contrast, once food can be stockpiled, a political elite can gain control of food produced by others, assert the right of taxation, escape the need to feed itself, and engage full-time in political activities. Hence moderate-sized agricultural societies are often organized in chiefdoms, and kingdoms are confined to large agricultural societies. Those complex political units are much better able to mount a sustained war of conquest than is an egalitarian band of hunters. Some hunter-gatherers in especially rich environments, such as the Pacific Northwest coast of North America and the coast of Ecuador, also developed sedentary societies, food storage, and nascent chiefdoms, but they did not go farther on the road to kingdoms.

A stored food surplus built up by taxation can support other full-time specialists besides kings and bureaucrats. Of most direct relevance to wars of conquest, it can be used to feed professional soldiers. That was the decisive factor in the British Empire's eventual defeat of New Zealand's well-armed indigenous Maori population. While the Maori achieved some stunning temporary victories, they could not maintain an army constantly in the field and were in the end worn down by 18,000 full-time British troops. Stored food can also feed priests, who provide religious justification for wars of conquest; artisans such as metalworkers, who develop swords, guns, and other technologies; and scribes, who preserve far more information than can be remembered accurately.

So far, I've emphasized direct and indirect values of crops and livestock as food. However, they have other uses, such as keeping us warm and providing us with valuable materials. Crops and livestock yield natural fibers for making clothing, blankets, nets, and rope. Most of the major centers of plant domestication evolved not only food crops but also fiber crops—notably cotton, flax (the source of linen), and hemp. Several domestic animals yielded animal fibers—especially wool from sheep, goats, llamas, and alpacas, and silk from silkworms. Bones of domestic animals were important raw materials for artifacts of Neolithic peoples before the development of metallurgy. Cow hides were used to make leather. One of the earliest cultivated plants in many parts of the Americas was grown for nonfood purposes: the bottle gourd, used as a container.

Big domestic mammals further revolutionized human society by becoming our main means of land transport until the development of railroads in the 19th century. Before animal domestication, the sole means of transporting goods and people by land was on the backs of humans. Large mammals changed that: for the first time in human history, it became possible to move heavy goods in large quantities, as well as people, rapidly overland for long distances. The domestic animals that were ridden were the horse, donkey, yak, reindeer, and Arabian and Bactrian camels. Animals of those same five species, as well as the llama, were used to bear packs. Cows and horses were hitched to wagons, while reindeer and dogs pulled sleds in the Arctic. The horse became the chief means of long-distance transport over most of Eurasia. The three domestic camel species (Arabian camel, Bactrian camel, and llama) played a similar role in areas of North Africa and Arabia, Central Asia, and the Andes, respectively.

The most direct contribution of plant and animal domestication to wars of conquest was from Eurasia's horses, whose military role made them the jeeps and Sherman tanks of ancient warfare on that continent. As I mentioned in Chapter 3, they enabled Cortés and Pizarro, leading only small bands of adventurers, to overthrow the Aztec and Inca Empires. Even much earlier (around 4000 B.C.), at a time when horses were still ridden bareback, they may have been the essential military ingredient behind the westward expansion of speakers of Indo-European languages from the Ukraine. Those languages eventually replaced all earlier western European languages except Basque. When horses later were yoked to wagons and other vehicles, horse-drawn battle chariots (invented around 1800 B.C.) proceeded to revolutionize warfare in the Near East, the Mediterranean region, and China. For example, in 1674 B.C., horses even enabled a foreign people, the Hyksos, to conquer then horseless Egypt and to establish themselves temporarily as pharaohs.

Still later, after the invention of saddles and stirrups, horses allowed the Huns and successive waves of other peoples from the Asian steppes to terrorize the Roman Empire and its successor states, culminating in the Mongol conquests of much of Asia and Russia in the 13th and 14th centuries A.D. Only with the introduction of trucks and tanks in World War I did horses finally become supplanted as the main assault vehicle and means of fast transport in war. Arabian and Bactrian camels played a similar military role within their geographic range. In all these examples, peoples with domestic horses (or camels), or with improved means of using them, enjoyed an enormous military advantage over those without them.

Of equal importance in wars of conquest were the germs that evolved in human societies with domestic animals. Infectious diseases like smallpox, measles, and flu arose as specialized germs of humans, derived by mutations of very similar ancestral germs that had infected animals (Chapter 11). The humans who domesticated animals were the first to fall victim to the newly evolved germs, but those humans then evolved substantial resistance to the new diseases. When such partly immune people came into contact with others who had had no previous exposure to the germs, epidemics resulted in which up to 99 percent of the previously unexposed population was killed. Germs thus acquired ultimately from domestic animals played decisive roles in the European conquests of Native Americans, Australians, South Africans, and Pacific islanders.

In short, plant and animal domestication meant much more food and hence much denser human populations. The resulting food surpluses, and (in some areas) the animal-based means of transporting those surpluses, were a prerequisite for the development of settled, politically centralized, socially stratified, economically complex, technologically innovative societies. Hence the availability of domestic plants and animals ultimately explains why empires, literacy, and steel weapons developed earliest in Eurasia and later, or not at all, on other continents. The military uses of horses and camels, and the killing power of animal-derived germs, complete the list of major links between food production and conquest that we shall be exploring.

CHAPTER 5

HISTORY'S HAVES AND HAVE-NOTS

MUCH OF HUMAN HISTORY HAS CONSISTED OF UNEQUAL conflicts between the haves and the have-nots: between peoples with farmer power and those without it, or between those who acquired it at different times. It should come as no surprise that food production never arose in large areas of the globe, for ecological reasons that still make it difficult or impossible there today. For instance, neither farming nor herding developed in prehistoric times in North America's Arctic, while the sole element of food production to arise in Eurasia's Arctic was reindeer herding. Nor could food production spring up spontaneously in deserts remote from sources of water for irrigation, such as central Australia and parts of the western United States.

Instead, what cries out for explanation is the failure of food production to appear, until modern times, in some ecologically very suitable areas that are among the world's richest centers of agriculture and herding today. Foremost among these puzzling areas, where indigenous peoples were still hunter-gatherers when European colonists arrived, were California and the other Pacific states of the United States, the Argentine pampas, southwestern and southeastern Australia, and much of the Cape region of South Africa. Had we surveyed the world in 4000 B.C., thousands of years after the rise of food production in its oldest sites of origin, we would have been surprised too at several other modern breadbaskets that were still then without it—including all the rest of the United States, England and much of France, Indonesia, and all of subequatorial Africa. When we trace food production back to its beginnings, the earliest sites provide another surprise. Far from being modern breadbaskets, they include areas ranking today as somewhat dry or ecologically degraded: Iraq and Iran, Mexico, the Andes, parts of China, and Africa's Sahel zone. Why did food production develop first in these seemingly rather marginal lands, and only later in today's most fertile farmlands and pastures?

Geographic differences in the means by which food production arose are also puzzling. In a few places it developed independently, as a result of local people domesticating local plants and animals. In most other places it was instead imported, in the form of crops and livestock that had been domesticated elsewhere. Since those areas of nonindependent origins were suitable for prehistoric food production as soon as domesticates had arrived, why did the peoples of those areas not become farmers and herders without outside assistance, by domesticating local plants and animals?

Among those regions where food production did spring up independently, why did the times at which it appeared vary so greatly—for example, thousands of years earlier in eastern Asia than in the eastern United States and never in eastern Australia? Among those regions into which it was imported in the prehistoric era, why did the date of arrival also vary so greatly—for example, thousands of years earlier in southwestern Europe than in the southwestern United States? Again among those regions where it was imported, why in some areas (such as the southwestern United States) did local hunter-gatherers themselves adopt crops and livestock from neighbors and survive as farmers, while in other areas (such as Indonesia and much of subequatorial Africa) the importation of food production involved a cataclysmic replacement of the region's original hunter-gatherers by invading food producers? All these questions involve developments that determined which peoples became history's have-nots, and which became its haves.

BEFORE WE CAN hope to answer these questions, we need to figure out how to identify areas where food production originated, when it arose there, and where and when a given crop or animal was first domesticated. The most unequivocal evidence comes from identification of plant and animal remains at archaeological sites. Most domesticated plant and animal species differ morphologically from their wild ancestors: for example, in the smaller size of domestic cattle and sheep, the larger size of domestic chickens and apples, the thinner and smoother seed coats of domestic peas, and the corkscrew-twisted rather than scimitar-shaped horns of domestic goats. Hence remains of domesticated plants and animals at a dated archaeological site can be recognized and provide strong evidence of food production at that place and time, whereas finding the remains only of wild species at a site fails to provide evidence of food production and is compatible with hunting-gathering. Naturally, food producers, especially early ones, continued to gather some wild plants and hunt wild animals, so the food remains at their sites often include wild species as well as domesticated ones.

Archaeologists date food production by radiocarbon dating of carbon-containing materials at the site. This method is based on the slow decay of radioactive carbon 14, a very minor component of carbon, the ubiquitous building block of life, into the nonradioactive isotope nitrogen 14. Carbon 14 is continually being generated in the atmosphere by cosmic rays. Plants take up atmospheric carbon, which has a known and approximately constant ratio of carbon 14 to the prevalent isotope carbon 12 (a ratio of about one to a million). That plant carbon goes on to form the body of the herbivorous animals that eat the plants, and of the carnivorous animals that eat those herbivorous animals. Once the plant or animal dies, though, half of its carbon 14 content decays into carbon 12 every 5,700 years, until after about 40,000 years the carbon 14 content is very low and difficult to measure or to distinguish from contamination with small amounts of modern materials containing carbon 14. Hence the age of material from an archaeological site can be calculated from the material's carbon 14 / carbon 12 ratio.

Radiocarbon is plagued by numerous technical problems, of which two deserve mention here. One is that radiocarbon dating until the 1980s required relatively large amounts of carbon (a few grams), much more than the amount in small seeds or bones. Hence scientists instead often had to resort to dating material recovered nearby at the same site and believed to be "associated with" the food remains—that is, to have been deposited simultaneously by the people who left the food. A typical choice of "associated" material is charcoal from fires.

But archaeological sites are not always neatly sealed time capsules of materials all deposited on the same day. Materials deposited at different times can get mixed together, as worms and rodents and other agents churn up the ground. Charcoal residues from a fire can thereby end up close to the remains of a plant or animal that died and was eaten thousands of years earlier or later. Increasingly today, archaeologists are circumventing this problem by a new technique termed accelerator mass spectrometry, which permits radiocarbon dating of tiny samples and thus lets one directly date a single small seed, small bone, or other food residue. In some cases big differences have been found between recent radiocarbon dates based on the direct new methods (which have their own problems) and those based on the indirect older ones. Among the resulting controversies remaining unresolved, perhaps the most important for the purposes of this book concerns the date when food production originated in the Americas: indirect methods of the 1960s and 1970s yielded dates as early as 7000 B.C., but more recent direct dating has been yielding dates no earlier than 3500 B.C.

A second problem in radiocarbon dating is that the carbon 14 / carbon 12 ratio of the atmosphere is in fact not rigidly constant but fluctuates slightly with time, so calculations of radiocarbon dates based on the assumption of a constant ratio are subject to small systematic errors. The magnitude of this error for each past date can in principle be determined with the help of long-lived trees laying down annual growth rings, since the rings can be counted up to obtain an absolute calendar date in the past for each ring, and a carbon sample of wood dated in this manner can then be analyzed for its carbon 14 / carbon 12 ratio. In this way, measured radiocarbon dates can be "calibrated" to take account of fluctuations in the atmospheric carbon ratio. The effect of this correction is that, for materials with apparent (that is, uncalibrated) dates between about 1000 and 6000 B.C., the true (calibrated) date is between a few centuries and a thousand years earlier. Somewhat older samples have more recently begun to be calibrated by an alternative method based on another radioactive decay process and yielding the conclusion that samples apparently dating to about 9000 B.C. actually date to around 11,000 B.C.

Archaeologists often distinguish calibrated from uncalibrated dates by writing the former in upper-case letters and the latter in lower-case letters (for example, 3000 B.C. vs. 3000 b.c., respectively). However, the archaeological literature can be confusing in this respect, because many books and papers report *un*calibrated dates as B.C. and fail to mention that they are

Plate 1. Large stone spear points used by Clovis hunters, who were widespread in North America around 13,000 years ago.

Plate 16. Re-creation of the Battle of Cajamarca in 1532, when 169 Spaniards defeated an Inca army of 80,000 and captured the Inca emperor Atahuallpa.

actually uncalibrated. The dates that I report in this book for events within the last 15,000 years are calibrated dates. That accounts for some of the discrepancies that readers may note between this book's dates and those quoted in some standard reference books on early food production.

Once one has recognized and dated ancient remains of domestic plants or animals, how does one decide whether the plant or animal was actually domesticated in the vicinity of that site itself, rather than domesticated elsewhere and then spread to the site? One method is to examine a map of the geographic distribution of the crop's or animal's wild ancestor, and to reason that domestication must have taken place in the area where the wild ancestor occurs. For example, chickpeas are widely grown by traditional farmers from the Mediterranean and Ethiopia east to India, with the latter country accounting for 80 percent of the world's chickpea production today. One might therefore have been deceived into supposing that chickpeas were domesticated in India. But it turns out that ancestral wild chickpeas occur only in southeastern Turkey. The interpretation that chickpeas were actually domesticated there is supported by the fact that the oldest finds of possibly domesticated chickpeas in Neolithic archaeological sites come from southeastern Turkey and nearby northern Syria that date to around 8000 B.C.; not until over 5,000 years later does archaeological evidence of chickpeas appear on the Indian subcontinent.

A second method for identifying a crop's or animal's site of domestication is to plot on a map the dates of the domesticated form's first appearance at each locality. The site where it appeared earliest may be its site of initial domestication—especially if the wild ancestor also occurred there, and if the dates of first appearance at other sites become progressively later with increasing distance from the putative site of initial domestication, suggesting spread to those other sites. For instance, the earliest known cultivated emmer wheat comes from the Fertile Crescent around 8500 B.C. Soon thereafter, the crop appears progressively farther west, reaching Greece around 6500 B.C. and Germany around 5000 B.C. Those dates suggest domestication of emmer wheat in the Fertile Crescent, a conclusion supported by the fact that ancestral wild emmer wheat is confined to the area extending from Israel to western Iran and Turkey.

However, as we shall see, complications arise in many cases where the same plant or animal was domesticated independently at several different sites. Such cases can often be detected by analyzing the resulting morphological, genetic, or chromosomal differences between specimens of the same crop or domestic animal in different areas. For instance, India's zebu breeds of domestic cattle possess humps lacking in western Eurasian cattle breeds, and genetic analyses show that the ancestors of modern Indian and western Eurasian cattle breeds diverged from each other hundreds of thousands of years ago, long before any animals were domesticated anywhere. That is, cattle were domesticated independently in India and western Eurasia, within the last 10,000 years, starting with wild Indian and western Eurasian cattle subspecies that had diverged hundreds of thousands of years earlier.

LET'S NOW RETURN to our earlier questions about the rise of food production. Where, when, and how did food production develop in different parts of the globe?

At one extreme are areas in which food production arose altogether independently, with the domestication of many indigenous crops (and, in some cases, animals) before the arrival of any crops or animals from other areas. There are only five such areas for which the evidence is at present detailed and compelling: Southwest Asia, also known as the Near East or Fertile Crescent; China; Mesoamerica (the term applied to central and southern Mexico and adjacent areas of Central America); the Andes of South America, and possibly the adjacent Amazon Basin as well; and the eastern United States (Figure 5.1). Some or all of these centers may actually comprise several nearby centers where food production arose more or less independently, such as North China's Yellow River valley and South China's Yangtze River valley.

In addition to these five areas where food production definitely arose de novo, four others—Africa's Sahel zone, tropical West Africa, Ethiopia, and New Guinea—are candidates for that distinction. However, there is some uncertainty in each case. Although indigenous wild plants were undoubtedly domesticated in Africa's Sahel zone just south of the Sahara, cattle herding may have preceded agriculture there, and it is not yet certain whether those were independently domesticated Sahel cattle or, instead, domestic cattle of Fertile Crescent origin whose arrival triggered local plant domestication. It remains similarly uncertain whether the arrival of those Sahel crops then triggered the undoubted local domestication of indigenous wild plants in tropical West Africa, and whether the arrival of Southwest Asian crops is what triggered the local domestication of indigenous wild plants in Ethiopia. As for New Guinea, archaeological studies there have provided evidence of early agriculture well before food production in any adjacent areas, but the crops grown have not been definitely identified.

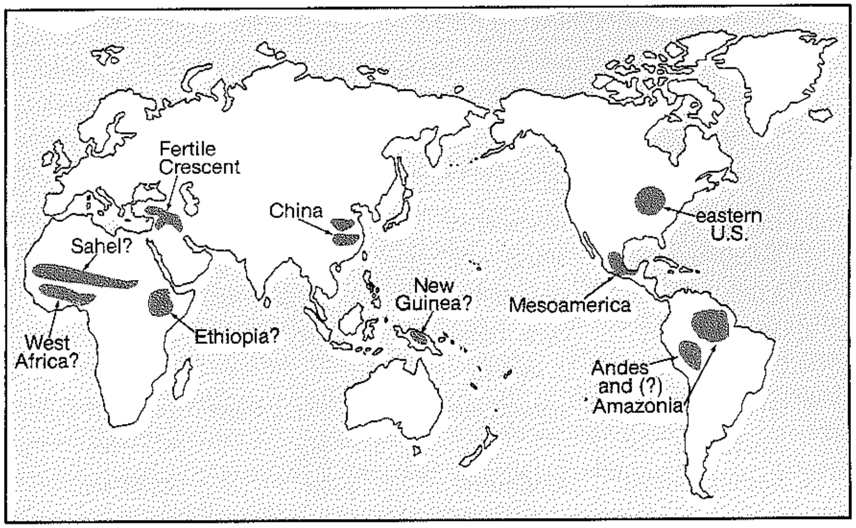

Figure 5.1. Centers of origin of food production. A question mark indicates some uncertainty whether the rise of food production at that center was really uninfluenced by the spread of food production from other centers, or (in the case of New Guinea) what the earliest crops were.

Table 5.1 summarizes, for these and other areas of local domestication, some of the best-known crops and animals and the earliest known dates of domestication. Among these nine candidate areas for the independent evolution of food production, Southwest Asia has the earliest definite dates for both plant domestication (around 8500 B.C.) and animal domestication (around 8000 B.C.); it also has by far the largest number of accurate radiocarbon dates for early food production. Dates for China are nearly as early, while dates for the eastern United States are clearly about 6,000 years later. For the other six candidate areas, the earliest well-established dates do not rival those for Southwest Asia, but too few early sites have been securely dated in those six other areas for us to be certain that they really lagged behind Southwest Asia and (if so) by how much.

The next group of areas consists of ones that did domesticate at least a

TABLE 5.1 Examples of Species Domesticated in Each Area

Area	*Domesticated*		*Earliest Attested Date of Domestication*
	Plants	*Animals*	
Independent Origins of Domestication			
1. Southwest Asia	wheat, pea, olive	sheep, goat	8500 B.C.
2. China	rice, millet	pig, silkworm	by 7500 B.C.
3. Mesoamerica	corn, beans, squash	turkey	by 3500 B.C.
4. Andes and Amazonia	potato, manioc	llama, guinea pig	by 3500 B.C.
5. Eastern United States	sunflower, goosefoot	none	2500 B.C.
? 6. Sahel	sorghum, African rice	guinea fowl	by 5000 B.C.
? 7. Tropical West Africa	African yams, oil palm	none	by 3000 B.C.
? 8. Ethiopia	coffee, teff	none	?
? 9. New Guinea	sugar cane, banana	none	7000 B.C.?
Local Domestication Following Arrival of Founder Crops from Elsewhere			
10. Western Europe	poppy, oat	none	6000–3500 B.C.
11. Indus Valley	sesame, eggplant	humped cattle	7000 B.C.
12. Egypt	sycamore fig, chufa	donkey, cat	6000 B.C.

couple of local plants or animals, but where food production depended mainly on crops and animals that were domesticated elsewhere. Those imported domesticates may be thought of as "founder" crops and animals, because they founded local food production. The arrival of founder domesticates enabled local people to become sedentary, and thereby increased the likelihood of local crops' evolving from wild plants that were gathered, brought home and planted accidentally, and later planted intentionally.

In three or four such areas, the arriving founder package came from Southwest Asia. One of them is western and central Europe, where food production arose with the arrival of Southwest Asian crops and animals between 6000 and 3500 B.C., but at least one plant (the poppy, and probably oats and some others) was then domesticated locally. Wild poppies are confined to coastal areas of the western Mediterranean. Poppy seeds are absent from excavated sites of the earliest farming communities in eastern Europe and Southwest Asia; they first appear in early farming sites in western Europe. In contrast, the wild ancestors of most Southwest Asian crops and animals were absent from western Europe. Thus, it seems clear that food production did not evolve independently in western Europe. Instead, it was triggered there by the arrival of Southwest Asian domesticates. The resulting western European farming societies domesticated the poppy, which subsequently spread eastward as a crop.

Another area where local domestication appears to have followed the arrival of Southwest Asian founder crops is the Indus Valley region of the Indian subcontinent. The earliest farming communities there in the seventh millennium B.C. utilized wheat, barley, and other crops that had been previously domesticated in the Fertile Crescent and that evidently spread to the Indus Valley through Iran. Only later did domesticates derived from indigenous species of the Indian subcontinent, such as humped cattle and sesame, appear in Indus Valley farming communities. In Egypt as well, food production began in the sixth millennium B.C. with the arrival of Southwest Asian crops. Egyptians then domesticated the sycamore fig and a local vegetable called chufa.

The same pattern perhaps applies to Ethiopia, where wheat, barley, and other Southwest Asian crops have been cultivated for a long time. Ethiopians also domesticated many locally available wild species to obtain crops most of which are still confined to Ethiopia, but one of them (the coffee bean) has now spread around the world. However, it is not yet known whether Ethiopians were cultivating these local plants before or only after the arrival of the Southwest Asian package.

In these and other areas where food production depended on the arrival of founder crops from elsewhere, did local hunter-gatherers themselves adopt those founder crops from neighboring farming peoples and thereby become farmers themselves? Or was the founder package instead brought by invading farmers, who were thereby enabled to outbreed the local hunters and to kill, displace, or outnumber them?

In Egypt it seems likely that the former happened: local hunter-gatherers simply added Southwest Asian domesticates and farming and herding techniques to their own diet of wild plants and animals, then gradually phased out the wild foods. That is, what arrived to launch food production in Egypt was foreign crops and animals, not foreign peoples. The same may have been true on the Atlantic coast of Europe, where local hunter-gatherers apparently adopted Southwest Asian sheep and cereals over the course of many centuries. In the Cape of South Africa the local Khoi hunter-gatherers became herders (but not farmers) by acquiring sheep and cows from farther north in Africa (and ultimately from Southwest Asia). Similarly, Native American hunter-gatherers of the U.S. Southwest gradually became farmers by acquiring Mexican crops. In these four areas the onset of food production provides little or no evidence for the domestication of local plant or animal species, but also little or no evidence for the replacement of human population.

At the opposite extreme are regions in which food production certainly began with an abrupt arrival of foreign people as well as of foreign crops and animals. The reason why we can be certain is that the arrivals took place in modern times and involved literate Europeans, who described in innumerable books what happened. Those areas include California, the Pacific Northwest of North America, the Argentine pampas, Australia, and Siberia. Until recent centuries, these areas were still occupied by hunter-gatherers—Native Americans in the first three cases and Aboriginal Australians or Native Siberians in the last two. Those hunter-gatherers were killed, infected, driven out, or largely replaced by arriving European farmers and herders who brought their own crops and did not domesticate any local wild species after their arrival (except for macadamia nuts in Australia). In the Cape of South Africa the arriving Europeans found not only Khoi hunter-gatherers but also Khoi herders who already possessed only domestic animals, not crops. The result was again the start of farming dependent on crops from elsewhere, a failure to domesticate local species, and a massive modern replacement of human population.

Finally, the same pattern of an abrupt start of food production dependent on domesticates from elsewhere, and an abrupt and massive population replacement, seems to have repeated itself in many areas in the prehistoric era. In the absence of written records, the evidence of those prehistoric replacements must be sought in the archaeological record or inferred from linguistic evidence. The best-attested cases are ones in which there can be no doubt about population replacement because the newly arriving food producers differed markedly in their skeletons from the hunter-gatherers whom they replaced, and because the food producers introduced not only crops and animals but also pottery. Later chapters will describe the two clearest such examples: the Austronesian expansion from South China into the Philippines and Indonesia (Chapter 17), and the Bantu expansion over subequatorial Africa (Chapter 19).

Southeastern Europe and central Europe present a similar picture of an abrupt onset of food production (dependent on Southwest Asian crops and animals) and of pottery making. This onset too probably involved replacement of old Greeks and Germans by new Greeks and Germans, just as old gave way to new in the Philippines, Indonesia, and subequatorial Africa. However, the skeletal differences between the earlier hunter-gatherers and the farmers who replaced them are less marked in Europe than in the Philippines, Indonesia, and subequatorial Africa. Hence the case for population replacement in Europe is less strong or less direct.

IN SHORT, ONLY a few areas of the world developed food production independently, and they did so at widely differing times. From those nuclear areas, hunter-gatherers of some neighboring areas learned food production, and peoples of other neighboring areas were replaced by invading food producers from the nuclear areas—again at widely differing times. Finally, peoples of some areas ecologically suitable for food production neither evolved nor acquired agriculture in prehistoric times at all; they persisted as hunter-gatherers until the modern world finally swept upon them. The peoples of areas with a head start on food production thereby gained a head start on the path leading toward guns, germs, and steel. The result was a long series of collisions between the haves and the have-nots of history.

How can we explain these geographic differences in the times and modes of onset of food production? That question, one of the most important problems of prehistory, will be the subject of the next five chapters.

CHAPTER 6

TO FARM OR NOT TO FARM

FORMERLY, ALL PEOPLE ON EARTH WERE HUNTER-GATHERERS. Why did any of them adopt food production at all? Given that they must have had some reason, why did they do so around 8500 B.C. in Mediterranean habitats of the Fertile Crescent, only 3,000 years later in the climatically and structurally similar Mediterranean habitats of southwestern Europe, and never indigenously in the similar Mediterranean habitats of California, southwestern Australia, and the Cape of South Africa? Why did even people of the Fertile Crescent wait until 8500 B.C., instead of becoming food producers already around 18,500 or 28,500 B.C.?

From our modern perspective, all these questions at first seem silly, because the drawbacks of being a hunter-gatherer appear so obvious. Scientists used to quote a phrase of Thomas Hobbes's in order to characterize the lifestyle of hunter-gatherers as "nasty, brutish, and short." They seemed to have to work hard, to be driven by the daily quest for food, often to be close to starvation, to lack such elementary material comforts as soft beds and adequate clothing, and to die young.

In reality, only for today's affluent First World citizens, who don't actually do the work of raising food themselves, does food production (by remote agribusinesses) mean less physical work, more comfort, freedom from starvation, and a longer expected lifetime. Most peasant farmers and

herders, who constitute the great majority of the world's actual food producers, aren't necessarily better off than hunter-gatherers. Time budget studies show that they may spend more rather than fewer hours per day at work than hunter-gatherers do. Archaeologists have demonstrated that the first farmers in many areas were smaller and less well nourished, suffered from more serious diseases, and died on the average at a younger age than the hunter-gatherers they replaced. If those first farmers could have foreseen the consequences of adopting food production, they might not have opted to do so. Why, unable to foresee the result, did they nevertheless make that choice?

There exist many actual cases of hunter-gatherers who did see food production practiced by their neighbors, and who nevertheless refused to accept its supposed blessings and instead remained hunter-gatherers. For instance, Aboriginal hunter-gatherers of northeastern Australia traded for thousands of years with farmers of the Torres Strait Islands, between Australia and New Guinea. California Native American hunter-gatherers traded with Native American farmers in the Colorado River valley. In addition, Khoi herders west of the Fish River of South Africa traded with Bantu farmers east of the Fish River, and continued to dispense with farming themselves. Why?

Still other hunter-gatherers in contact with farmers did eventually become farmers, but only after what may seem to us like an inordinately long delay. For example, the coastal peoples of northern Germany did not adopt food production until 1,300 years after peoples of the Linearbandkeramik culture introduced it to inland parts of Germany only 125 miles to the south. Why did those coastal Germans wait so long, and what led them finally to change their minds?

BEFORE WE CAN answer these questions, we must dispel some misconceptions about the origins of food production and then reformulate the question. What actually happened was not a *discovery* of food production, nor an *invention*, as we might first assume. There was often not even a conscious choice between food production and hunting-gathering. Specifically, in each area of the globe the first people who adopted food production could obviously not have been making a conscious choice or consciously striving toward farming as a goal, because they had never seen farming and had no way of knowing what it would be like. Instead, as we shall see, food production *evolved* as a by-product of decisions made without awareness of their consequences. Hence the question that we have to ask is why food production did evolve, why it evolved in some places but not others, why at different times in different places, and why not instead at some earlier or later date.

Another misconception is that there is necessarily a sharp divide between nomadic hunter-gatherers and sedentary food producers. In reality, although we frequently draw such a contrast, hunter-gatherers in some productive areas, including North America's Pacific Northwest coast and possibly southeastern Australia, became sedentary but never became food producers. Other hunter-gatherers, in Palestine, coastal Peru, and Japan, became sedentary first and adopted food production much later. Sedentary groups probably made up a much higher fraction of hunter-gatherers 15,000 years ago, when all inhabited parts of the world (including the most productive areas) were still occupied by hunter-gatherers, than they do today, when the few remaining hunter-gatherers survive only in unproductive areas where nomadism is the sole option.

Conversely, there are mobile groups of food producers. Some modern nomads of New Guinea's Lakes Plains make clearings in the jungle, plant bananas and papayas, go off for a few months to live again as hunter-gatherers, return to check on their crops, weed the garden if they find the crops growing, set off again to hunt, return months later to check again, and settle down for a while to harvest and eat if their garden has produced. Apache Indians of the southwestern United States settled down to farm in the summer at higher elevations and toward the north, then withdrew to the south and to lower elevations to wander in search of wild foods during the winter. Many herding peoples of Africa and Asia shift camp along regular seasonal routes to take advantage of predictable seasonal changes in pasturage. Thus, the shift from hunting-gathering to food production did not always coincide with a shift from nomadism to sedentary living.

Another supposed dichotomy that becomes blurred in reality is a distinction between food producers as active managers of their land and hunter-gatherers as mere collectors of the land's wild produce. In reality, some hunter-gatherers intensively manage their land. For example, New Guinea peoples who never domesticated sago palms or mountain pandanus nevertheless increase production of these wild edible plants by clearing away encroaching competing trees, keeping channels in sago swamps clear, and promoting growth of new sago shoots by cutting down mature

sago trees. Aboriginal Australians who never reached the stage of farming yams and seed plants nonetheless anticipated several elements of farming. They managed the landscape by burning it, to encourage the growth of edible seed plants that sprout after fires. In gathering wild yams, they cut off most of the edible tuber but replaced the stems and tops of the tubers in the ground so that the tubers would regrow. Their digging to extract the tuber loosened and aerated the soil and fostered regrowth. All that they would have had to do to meet the definition of farmers was to carry the stems and remaining attached tubers home and similarly replace them in soil at their camp.

FROM THOSE PRECURSORS of food production already practiced by hunter-gatherers, it developed stepwise. Not all the necessary techniques were developed within a short time, and not all the wild plants and animals that were eventually domesticated in a given area were domesticated simultaneously. Even in the cases of the most rapid independent development of food production from a hunting-gathering lifestyle, it took thousands of years to shift from complete dependence on wild foods to a diet with very few wild foods. In early stages of food production, people simultaneously collected wild foods *and* raised cultivated ones, and diverse types of collecting activities diminished in importance at different times as reliance on crops increased.

The underlying reason why this transition was piecemeal is that food production systems evolved as a result of the accumulation of many separate decisions about allocating time and effort. Foraging humans, like foraging animals, have only finite time and energy, which they can spend in various ways. We can picture an incipient farmer waking up and asking: Shall I spend today hoeing my garden (predictably yielding a lot of vegetables several months from now), gathering shellfish (predictably yielding a little meat today), or hunting deer (yielding possibly a lot of meat today, but more likely nothing)? Human and animal foragers are constantly prioritizing and making effort-allocation decisions, even if only unconsciously. They concentrate first on favorite foods, or ones that yield the highest payoff. If these are unavailable, they shift to less and less preferred foods.

Many considerations enter into these decisions. People seek food in order to satisfy their hunger and fill their bellies. They also crave specific foods, such as protein-rich foods, fat, salt, sweet fruits, and foods that simply taste good. All other things being equal, people seek to maximize their return of calories, protein, or other specific food categories by foraging in a way that yields the most return with the greatest certainty in the least time for the least effort. Simultaneously, they seek to minimize their risk of starving: moderate but reliable returns are preferable to a fluctuating lifestyle with a high time-averaged rate of return but a substantial likelihood of starving to death. One suggested function of the first gardens of nearly 11,000 years ago was to provide a reliable reserve larder as insurance in case wild food supplies failed.

Conversely, men hunters tend to guide themselves by considerations of prestige: for example, they might rather go giraffe hunting every day, bag a giraffe once a month, and thereby gain the status of great hunter, than bring home twice a giraffe's weight of food in a month by humbling themselves and reliably gathering nuts every day. People are also guided by seemingly arbitrary cultural preferences, such as considering fish either delicacies or taboo. Finally, their priorities are heavily influenced by the relative values they attach to different lifestyles—just as we can see today. For instance, in the 19th-century U.S. West, the cattlemen, sheepmen, and farmers all despised each other. Similarly, throughout human history farmers have tended to despise hunter-gatherers as primitive, hunter-gatherers have despised farmers as ignorant, and herders have despised both. All these elements come into play in people's separate decisions about how to obtain their food.

AS WE ALREADY noted, the first farmers on each continent could not have chosen farming consciously, because there were no other nearby farmers for them to observe. However, once food production had arisen in one part of a continent, neighboring hunter-gatherers could see the result and make conscious decisions. In some cases the hunter-gatherers adopted the neighboring system of food production virtually as a complete package; in others they chose only certain elements of it; and in still others they rejected food production entirely and remained hunter-gatherers.

For example, hunter-gatherers in parts of southeastern Europe had quickly adopted Southwest Asian cereal crops, pulse crops, and livestock simultaneously as a complete package by around 6000 B.C. All three of these elements also spread rapidly through central Europe in the centuries before 5000 B.C. Adoption of food production may have been rapid and

wholesale in southeastern and central Europe because the hunter-gatherer lifestyle there was less productive and less competitive. In contrast, food production was adopted piecemeal in southwestern Europe (southern France, Spain, and Italy), where sheep arrived first and cereals later. The adoption of intensive food production from the Asian mainland was also very slow and piecemeal in Japan, probably because the hunter-gatherer lifestyle based on seafood and local plants was so productive there.

Just as a hunting-gathering lifestyle can be traded piecemeal for a food-producing lifestyle, one system of food production can also be traded piecemeal for another. For example, Indians of the eastern United States were domesticating local plants by about 2500 B.C. but had trade connections with Mexican Indians who developed a more productive crop system based on the trinity of corn, squash, and beans. Eastern U.S. Indians adopted Mexican crops, and many of them discarded many of their local domesticates, piecemeal; squash was domesticated independently, corn arrived from Mexico around A.D. 200 but remained a minor crop until around A.D. 900, and beans arrived a century or two later. It even happened that food-production systems were abandoned in favor of hunting-gathering. For instance, around 3000 B.C. the hunter-gatherers of southern Sweden adopted farming based on Southwest Asian crops, but abandoned it around 2700 B.C. and reverted to hunting-gathering for 400 years before resuming farming.

ALL THESE CONSIDERATIONS make it clear that we should not suppose that the decision to adopt farming was made in a vacuum, as if the people had previously had no means to feed themselves. Instead, we must consider food production and hunting-gathering as *alternative strategies* competing with each other. Mixed economies that added certain crops or livestock to hunting-gathering also competed against both types of "pure" economies, and against mixed economies with higher or lower proportions of food production. Nevertheless, over the last 10,000 years, the predominant result has been a shift from hunting-gathering to food production. Hence we must ask: What were the factors that tipped the competitive advantage away from the former and toward the latter?

That question continues to be debated by archaeologists and anthropologists. One reason for its remaining unsettled is that different factors may have been decisive in different parts of the world. Another has been the problem of disentangling cause and effect in the rise of food production. However, five main contributing factors can still be identified; the controversies revolve mainly around their relative importance.

One factor is the decline in the availability of wild foods. The lifestyle of hunter-gatherers has become increasingly less rewarding over the past 13,000 years, as resources on which they depended (especially animal resources) have become less abundant or even disappeared. As we saw in Chapter 1, most large mammal species became extinct in North and South America at the end of the Pleistocene, and some became extinct in Eurasia and Africa, either because of climate changes or because of the rise in skill and numbers of human hunters. While the role of animal extinctions in eventually (after a long lag) nudging ancient Native Americans, Eurasians, and Africans toward food production can be debated, there are numerous incontrovertible cases on islands in more recent times. Only after the first Polynesian settlers had exterminated moas and decimated seal populations on New Zealand, and exterminated or decimated seabirds and land birds on other Polynesian islands, did they intensify their food production. For instance, although the Polynesians who colonized Easter Island around A.D. 500 brought chickens with them, chicken did not become a major food until wild birds and porpoises were no longer readily available as food. Similarly, a suggested contributing factor to the rise of animal domestication in the Fertile Crescent was the decline in abundance of the wild gazelles that had previously been a major source of meat for hunter-gatherers in that area.

A second factor is that, just as the depletion of wild game tended to make hunting-gathering less rewarding, an increased availability of domesticable wild plants made steps leading to plant domestication more rewarding. For instance, climate changes at the end of the Pleistocene in the Fertile Crescent greatly expanded the area of habitats with wild cereals, of which huge crops could be harvested in a short time. Those wild cereal harvests were precursors to the domestication of the earliest crops, the cereals wheat and barley, in the Fertile Crescent.

Still another factor tipping the balance away from hunting-gathering was the cumulative development of technologies on which food production would eventually depend—technologies for collecting, processing, and storing wild foods. What use can would-be farmers make of a ton of wheat grains on the stalk, if they have not first figured out how to harvest, husk, and store them? The necessary methods, implements, and facilities appeared rapidly in the Fertile Crescent after 11,000 B.C., having been invented for dealing with the newly available abundance of wild cereals.

Those inventions included sickles of flint blades cemented into wooden or bone handles, for harvesting wild grains; baskets in which to carry the grains home from the hillsides where they grew; mortars and pestles, or grinding slabs, to remove the husks; the technique of roasting grains so that they could be stored without sprouting; and underground storage pits, some of them plastered to make them waterproof. Evidence for all of these techniques becomes abundant at sites of hunter-gatherers in the Fertile Crescent after 11,000 B.C. All these techniques, though developed for the exploitation of wild cereals, were prerequisites to the planting of cereals as crops. These cumulative developments constituted the unconscious first steps of plant domestication.

A fourth factor was the two-way link between the rise in human population density and the rise in food production. In all parts of the world where adequate evidence is available, archaeologists find evidence of rising densities associated with the appearance of food production. Which was the cause and which the result? This is a long-debated chicken-or-egg problem: did a rise in human population density force people to turn to food production, or did food production permit a rise in human population density?

In principle, one expects the chain of causation to operate in both directions. As I've already discussed, food production tends to lead to increased population densities because it yields more edible calories per acre than does hunting-gathering. On the other hand, human population densities were gradually rising throughout the late Pleistocene anyway, thanks to improvements in human technology for collecting and processing wild foods. As population densities rose, food production became increasingly favored because it provided the increased food outputs needed to feed all those people.

That is, the adoption of food production exemplifies what is termed an autocatalytic process—one that catalyzes itself in a positive feedback cycle, going faster and faster once it has started. A gradual rise in population densities impelled people to obtain more food, by rewarding those who unconsciously took steps toward producing it. Once people began to produce food and become sedentary, they could shorten the birth spacing and produce still more people, requiring still more food. This bidirectional link between food production and population density explains the paradox that food production, while increasing the quantity of edible calories per acre, left the food producers less well nourished than the hunter-gatherers whom they succeeded. That paradox developed because human population densities rose slightly more steeply than did the availability of food.

Taken together, these four factors help us understand why the transition to food production in the Fertile Crescent began around 8500 B.C., not around 18,500 or 28,500 B.C. At the latter two dates hunting-gathering was still much more rewarding than incipient food production, because wild mammals were still abundant; wild cereals were not yet abundant; people had not yet developed the inventions necessary for collecting, processing, and storing cereals efficiently; and human population densities were not yet high enough for a large premium to be placed on extracting more calories per acre.

A final factor in the transition became decisive at geographic boundaries between hunter-gatherers and food producers. The much denser populations of food producers enabled them to displace or kill hunter-gatherers by their sheer numbers, not to mention the other advantages associated with food production (including technology, germs, and professional soldiers). In areas where there were only hunter-gatherers to begin with, those groups of hunter-gatherers who adopted food production outbred those who didn't.

As a result, in most areas of the globe suitable for food production, hunter-gatherers met one of two fates: either they were displaced by neighboring food producers, or else they survived only by adopting food production themselves. In places where they were already numerous or where geography retarded immigration by food producers, local hunter-gatherers did have time to adopt farming in prehistoric times and thus to survive as farmers. This may have happened in the U.S. Southwest, in the western Mediterranean, on the Atlantic coast of Europe, and in parts of Japan. However, in Indonesia, tropical Southeast Asia, most of subequatorial Africa, and probably in parts of Europe, the hunter-gatherers were replaced by farmers in the prehistoric era, whereas a similar replacement took place in modern times in Australia and much of the western United States.

Only where especially potent geographic or ecological barriers made immigration of food producers or diffusion of locally appropriate food-producing techniques very difficult were hunter-gatherers able to persist until modern times in areas suitable for food production. The three outstanding examples are the persistence of Native American hunter-gatherers in California, separated by deserts from the Native American farmers of Arizona; that of Khoisan hunter-gatherers at the Cape of South Africa, in a Mediterranean climate zone unsuitable for the equatorial crops of nearby Bantu farmers; and that of hunter-gatherers throughout the Australian continent, separated by narrow seas from the food producers of Indonesia and New Guinea. Those few peoples who remained hunter-gatherers into the 20th century escaped replacement by food producers because they were confined to areas not fit for food production, especially deserts and Arctic regions. Within the present decade, even they will have been seduced by the attractions of civilization, settled down under pressure from bureaucrats or missionaries, or succumbed to germs.

CHAPTER 7

HOW TO MAKE AN ALMOND

IF YOU'RE A HIKER WHOSE APPETITE IS JADED BY FARM-grown foods, it's fun to try eating wild foods. You know that some wild plants, such as wild strawberries and blueberries, are both tasty and safe to eat. They're sufficiently similar to familiar crops that you can easily recognize the wild berries, even though they're much smaller than those we grow. Adventurous hikers cautiously eat mushrooms, aware that many species can kill us. But not even ardent nut lovers eat wild almonds, of which a few dozen contain enough cyanide (the poison used in Nazi gas chambers) to kill us. The forest is full of many other plants deemed inedible.

Yet all crops arose from wild plant species. How did certain wild plants get turned into crops? That question is especially puzzling in regard to the many crops (like almonds) whose wild progenitors are lethal or bad-tasting, and to other crops (like corn) that look drastically different from their wild ancestors. What cavewoman or caveman ever got the idea of "domesticating" a plant, and how was it accomplished?

Plant domestication may be defined as growing a plant and thereby, consciously or unconsciously, causing it to change genetically from its wild ancestor in ways making it more useful to human consumers. Crop development is today a conscious, highly specialized effort carried out by professional scientists. They already know about the hundreds of existing crops and set out to develop yet another one. To achieve that goal, they plant many different seeds or roots, select the best progeny and plant their seeds, apply knowledge of genetics to develop good varieties that breed true, and perhaps even use the latest techniques of genetic engineering to transfer specific useful genes. At the Davis campus of the University of California, an entire department (the Department of Pomology) is devoted to apples and another (the Department of Viticulture and Enology) to grapes and wine.

But plant domestication goes back over 10,000 years. Early farmers surely didn't use molecular genetic techniques to arrive at their results. The first farmers didn't even have any existing crop as a model to inspire them to develop new ones. Hence they couldn't have known that, whatever they were doing, they would enjoy a tasty treat as a result.

How, then, did early farmers domesticate plants unwittingly? For example, how did they turn poisonous almonds into safe ones without knowing what they were doing? What changes did they actually make in wild plants, besides rendering some of them bigger or less poisonous? Even for valuable crops, the times of domestication vary greatly: for instance, peas were domesticated by 8000 B.C., olives around 4000 B.C., strawberries not until the Middle Ages, and pecans not until 1846. Many valuable wild plants yielding food prized by millions of people, such as oaks sought for their edible acorns in many parts of the world, remain untamed even today. What made some plants so much easier or more inviting to domesticate than others? Why did olive trees yield to Stone Age farmers, whereas oak trees continue to defeat our brightest agronomists?

LET'S BEGIN BY looking at domestication from the plant's point of view. As far as plants are concerned, we're just one of thousands of animal species that unconsciously "domesticate" plants.

Like all animal species (including humans), plants must spread their offspring to areas where they can thrive and pass on their parents' genes. Young animals disperse by walking or flying, but plants don't have that option, so they must somehow hitchhike. While some plant species have seeds adapted for being carried by the wind or for floating on water, many others trick an animal into carrying their seeds, by wrapping the seed in a tasty fruit and advertising the fruit's ripeness by its color or smell. The hungry animal plucks and swallows the fruit, walks or flies off, and then spits out or defecates the seed somewhere far from its parent tree. Seeds can in this manner be carried for thousands of miles.

It may come as a surprise to learn that plant seeds can resist digestion by your gut and nonetheless germinate out of your feces. But any adventurous readers who are not too squeamish can make the test and prove it for themselves. The seeds of many wild plant species actually *must* pass through an animal's gut before they can germinate. For instance, one African melon species is so well adapted to being eaten by a hyena-like animal called the aardvark that most melons of that species grow on the latrine sites of aardvarks.

As an example of how would-be plant hitchhikers attract animals, consider wild strawberries. When strawberry seeds are still young and not yet ready to be planted, the surrounding fruit is green, sour, and hard. When the seeds finally mature, the berries turn red, sweet, and tender. The change in the berries' color serves as a signal attracting birds like thrushes to pluck the berries and fly off, eventually to spit out or defecate the seeds.

Naturally, strawberry plants didn't set out with a conscious intent of attracting birds when, and only when, their seeds were ready to be dispersed. Neither did thrushes set out with the intent of domesticating strawberries. Instead, strawberry plants evolved through natural selection. The greener and more sour the young strawberry, the fewer the birds that destroyed the seeds by eating berries before the seeds were ready; the sweeter and redder the final strawberry, the more numerous the birds that dispersed its ripe seeds.

Countless other plants have fruits adapted to being eaten and dispersed by particular species of animals. Just as strawberries are adapted to birds, so acorns are adapted to squirrels, mangos to bats, and some sedges to ants. That fulfills part of our definition of plant domestication, as the genetic modification of an ancestral plant in ways that make it more useful to consumers. But no one would seriously describe this evolutionary process as domestication, because birds and bats and other animal consumers don't fulfill the other part of the definition: they don't consciously grow plants. In the same way, the early unconscious stages of crop evolution from wild plants consisted of plants evolving in ways that attracted humans to eat and disperse their fruit without yet intentionally growing them. Human latrines, like those of aardvarks, may have been a testing ground of the first unconscious crop breeders.

LATRINES ARE MERELY one of the many places where we accidentally sow the seeds of wild plants that we eat. When we gather edible wild plants and bring them home, some spill en route or at our houses. Some fruit rots while still containing perfectly good seeds, and gets thrown out uneaten into the garbage. As parts of the fruit that we actually take into our mouths, strawberry seeds are tiny and inevitably swallowed and defecated, but other seeds are large enough to be spat out. Thus, our spittoons and garbage dumps joined our latrines to form the first agricultural research laboratories.

At whichever such "lab" the seeds ended up, they tended to come from only certain individuals of edible plants—namely, those that we preferred to eat for one reason or another. From your berry-picking days, you know that you select particular berries or berry bushes. Eventually, when the first farmers began to sow seeds deliberately, they would inevitably sow those from the plants they had chosen to gather, even though they didn't understand the genetic principle that big berries have seeds likely to grow into bushes yielding more big berries.

So, when you wade into a thorny thicket amid the mosquitoes on a hot, humid day, you don't do it for just any strawberry bush. Even if unconsciously, you decide which bush looks most promising, and whether it's worth it at all. What are your unconscious criteria?

One criterion, of course, is size. You prefer large berries, because it's not worth your while to get sunburned and mosquito bitten for some lousy little berries. That provides part of the explanation why many crop plants have much bigger fruits than their wild ancestors do. It's especially familiar to us that supermarket strawberries and blueberries are gigantic compared with wild ones; those differences arose only in recent centuries.

Such size differences in other plants go back to the very beginnings of agriculture, when cultivated peas evolved through human selection to be 10 times heavier than wild peas. The little wild peas had been collected by hunter-gatherers for thousands of years, just as we collect little wild blueberries today, before the preferential harvesting and planting of the most appealing largest wild peas—that is, what we call farming—began automatically to contribute to increases in average pea size from generation to generation. Similarly, supermarket apples are typically around three inches in diameter, wild apples only one inch. The oldest corn cobs are barely more than half an inch long, but Mexican Indian farmers of A.D. 1500 already had developed six-inch cobs, and some modern cobs are one and a half feet long.

Another obvious difference between seeds that we grow and many of their wild ancestors is in bitterness. Many wild seeds evolved to be bitter, bad-tasting, or actually poisonous, in order to deter animals from eating them. Thus, natural selection acts oppositely on seeds and on fruits. Plants whose fruits are tasty get their seeds dispersed by animals, but the seed itself within the fruit has to be bad-tasting. Otherwise, the animal would also chew up the seed, and it couldn't sprout.

Almonds provide a striking example of bitter seeds and their change under domestication. Most wild almond seeds contain an intensely bitter chemical called amygdalin, which (as was already mentioned) breaks down to yield the poison cyanide. A snack of wild almonds can kill a person foolish enough to ignore the warning of the bitter taste. Since the first stage in unconscious domestication involves gathering seeds to eat, how on earth did domestication of wild almonds ever reach that first stage?

The explanation is that occasional individual almond trees have a mutation in a single gene that prevents them from synthesizing the bitter-tasting amygdalin. Such trees die out in the wild without leaving any progeny, because birds discover and eat all their seeds. But curious or hungry children of early farmers, nibbling wild plants around them, would eventually have sampled and noticed those nonbitter almond trees. (In the same way, European peasants today still recognize and appreciate occasional individual oak trees whose acorns are sweet rather than bitter.) Those nonbitter almond seeds are the only ones that ancient farmers would have planted, at first unintentionally in their garbage heaps and later intentionally in their orchards.

Already by 8000 B.C. wild almonds show up in excavated archaeological sites in Greece. By 3000 B.C. they were being domesticated in lands of the eastern Mediterranean. When the Egyptian king Tutankhamen died, around 1325 B.C., almonds were one of the foods left in his famous tomb to nourish him in the afterlife. Lima beans, watermelons, potatoes, eggplants, and cabbages are among the many other familiar crops whose wild ancestors were bitter or poisonous, and of which occasional sweet individuals must have sprouted around the latrines of ancient hikers.

While size and tastiness are the most obvious criteria by which human hunter-gatherers select wild plants, other criteria include fleshy or seedless fruits, oily seeds, and long fibers. Wild squashes and pumpkins have little or no fruit around their seeds, but the preferences of early farmers selected for squashes and pumpkins consisting of far more flesh than seeds. Cultivated bananas were selected long ago to be all flesh and no seed, thereby inspiring modern agricultural scientists to develop seedless oranges, grapes, and watermelons as well. Seedlessness provides a good example of how human selection can completely reverse the original evolved function of a wild fruit, which in nature serves as a vehicle for dispersing seeds.

In ancient times many plants were similarly selected for oily fruits or seeds. Among the earliest fruit trees domesticated in the Mediterranean world were olives, cultivated since around 4000 B.C. for their oil. Crop olives are not only bigger but also oilier than wild ones. Ancient farmers selected sesame, mustard, poppies, and flax as well for oily seeds, while modern plant scientists have done the same for sunflower, safflower, and cotton.

Before that recent development of cotton for oil, it was of course selected for its fibers, used to weave textiles. The fibers (termed lint) are hairs on the cotton seeds, and early farmers of both the Americas and the Old World independently selected different species of cotton for long lint. In flax and hemp, two other plants grown to supply the textiles of antiquity, the fibers come instead from the stem, and plants were selected for long, straight stems. While we think of most crops as being grown for food, flax is one of our oldest crops (domesticated by around 7000 B.C.). It furnished linen, which remained the chief textile of Europe until it became supplanted by cotton and synthetics after the Industrial Revolution.

SO FAR, ALL the changes that I've described in the evolution of wild plants into crops involve characters that early farmers could actually notice—such as fruit size, bitterness, fleshiness, and oiliness, and fiber length. By harvesting those individual wild plants possessing these desirable qualities to an exceptional degree, ancient peoples unconsciously dispersed the plants and set them on the road to domestication.

In addition, though, there were at least four other major types of change that did not involve berry pickers making visible choices. In these cases the berry pickers caused changes either by harvesting available plants while other plants remained unavailable for invisible reasons, or by changing the selective conditions acting on plants.

The first such change affected wild mechanisms for the dispersal of seeds. Many plants have specialized mechanisms that scatter seeds (and thereby prevent humans from gathering them efficiently). Only mutant seeds lacking those mechanisms would have been harvested and would thus have become the progenitors of crops.

A clear example involves peas, whose seeds (the peas we eat) come enclosed in a pod. Wild peas have to get out of the pod if they are to germinate. To achieve that result, pea plants evolved a gene that makes the pod explode, shooting out the peas onto the ground. Pods of occasional mutant peas don't explode. In the wild the mutant peas would die entombed in their pod on their parent plants, and only the popping pods would pass on their genes. But, conversely, the only pods available to humans to harvest would be the nonpopping ones left on the plant. Thus, once humans began bringing wild peas home to eat, there was immediate selection for that single-gene mutant. Similar nonpopping mutants were selected in lentils, flax, and poppies.

Instead of being enclosed in a poppable pod, wild wheat and barley seeds grow at the top of a stalk that spontaneously shatters, dropping the seeds to the ground where they can germinate. A single-gene mutation prevents the stalks from shattering. In the wild that mutation would be lethal to the plant, since the seeds would remain suspended in the air, unable to germinate and take root. But those mutant seeds would have been the ones waiting conveniently on the stalk to be harvested and brought home by humans. When humans then planted those harvested mutant seeds, any mutant seeds among the progeny again became available to the farmers to harvest and sow, while normal seeds among the progeny fell to the ground and became unavailable. Thus, human farmers reversed the direction of natural selection by 180 degrees: the formerly successful gene suddenly became lethal, and the lethal mutant became successful. Over 10,000 years ago, that unconscious selection for nonshattering wheat and barley stalks was apparently the first major human "improvement" in any plant. That change marked the beginning of agriculture in the Fertile Crescent.

The second type of change was even less visible to ancient hikers. For annual plants growing in an area with a very unpredictable climate, it could be lethal if all the seeds sprouted quickly and simultaneously. Were that to happen, the seedlings might all be killed by a single drought or frost, leaving no seeds to propagate the species. Hence many annual plants have evolved to hedge their bets by means of germination inhibitors, which make seeds initially dormant and spread out their germination over several years. In that way, even if most seedlings are killed by a bout of bad weather, some seeds will be left to germinate later.

A common bet-hedging adaptation by which wild plants achieve that result is to enclose their seeds in a thick coat or armor. The many wild plants with such adaptations include wheat, barley, peas, flax, and sunflowers. While such late-sprouting seeds still have the opportunity to germinate in the wild, consider what must have happened as farming developed. Early farmers would have discovered by trial and error that they could obtain higher yields by tilling and watering the soil and then sowing seeds. When that happened, seeds that immediately sprouted grew into plants whose seeds were harvested and planted in the next year. But many of the wild seeds did not immediately sprout, and they yielded no harvest.

Occasional mutant individuals among wild plants lacked thick seed coats or other inhibitors of germination. All such mutants promptly sprouted and yielded harvested mutant seeds. Early farmers wouldn't have noticed the difference, in the way that they did notice and selectively harvest big berries. But the cycle of sow / grow / harvest / sow would have selected immediately and unconsciously for the mutants. Like the changes in seed dispersal, these changes in germination inhibition characterize wheat, barley, peas, and many other crops compared with their wild ancestors.

The remaining major type of change invisible to early farmers involved plant reproduction. A general problem in crop development is that occasional mutant plant individuals are more useful to humans (for example, because of bigger or less bitter seeds) than are normal individuals. If those desirable mutants proceeded to interbreed with normal plants, the mutation would immediately be diluted or lost. Under what circumstances would it remain preserved for early farmers?

For plants that reproduce themselves, the mutant would automatically be preserved. That's true of plants that reproduce vegetatively (from a tuber or root of the parent plant), or that are hermaphrodites capable of fertilizing themselves. But the vast majority of wild plants don't reproduce that way. They're either hermaphrodites incapable of fertilizing themselves and forced to interbreed with other hermaphrodite individuals (my male part fertilizes your female part, your male part fertilizes my female part), or else they occur as separate male and female individuals, like all normal mammals. The former plants are termed self-incompatible hermaphrodites; the latter, dioecious species. Both were bad news for ancient farmers, who would thereby have promptly lost any favorable mutants without understanding why.

The solution involved another type of invisible change. Numerous plant mutations affect the reproductive system itself. Some mutant individuals developed fruit without even having to be pollinated, resulting in our seedless bananas, grapes, oranges, and pineapples. Some mutant hermaphrodites lost their self-incompatibility and became able to fertilize themselves—a process exemplified by many fruit trees such as plums, peaches, apples, apricots, and cherries. Some mutant grapes that normally would have had separate male and female individuals also became self-fertilizing hermaphrodites. By all these means, ancient farmers, who didn't understand plant reproductive biology, still ended up with useful crops that bred true and were worth replanting, instead of initially promising mutants whose worthless progeny were consigned to oblivion.

Thus, farmers selected from among individual plants on the basis not only of perceptible qualities like size and taste, but also of invisible features like seed dispersal mechanisms, germination inhibition, and reproductive biology. As a result, different plants became selected for quite different or even opposite features. Some plants (like sunflowers) were selected for much bigger seeds, while others (like bananas) were selected for tiny or even nonexistent seeds. Lettuce was selected for luxuriant leaves at the expense of seeds or fruit; wheat and sunflowers, for seeds at the expense of leaves; and squash, for fruit at the expense of leaves. Especially instructive are cases in which a single wild plant species was variously selected for different purposes and thereby gave rise to quite different-looking crops. Beets, grown already in Babylonian times for their leaves (like the modern beet varieties called chards), were then developed for their edible roots and finally (in the 18th century) for their sugar content (sugar beets). Ancestral cabbage plants, possibly grown originally for their oily seeds, underwent even greater diversification as they became variously selected for leaves (modern cabbage and kale), stems (kohlrabi), buds (brussels sprouts), or flower shoots (cauliflower and broccoli).

So far, we have been discussing transformations of wild plants into crops as a result of selection by farmers, consciously or unconsciously. That is, farmers initially selected seeds of certain wild plant individuals to bring into their gardens and then chose certain progeny seeds each year to grow in the next year's garden. But much of the transformation was also effected as a result of plants' selecting themselves. Darwin's phrase "natural selection" refers to certain individuals of a species surviving better, and / or reproducing more successfully, than competing individuals of the same species under natural conditions. In effect, the natural processes of differential survival and reproduction do the selecting. If the conditions change, different types of individuals may now survive or reproduce better and become "naturally selected," with the result that the population undergoes evolutionary change. A classic example is the development of industrial melanism in British moths: darker moth individuals became relatively commoner than paler individuals as the environment became dirtier during the 19th century, because dark moths resting on a dark, dirty tree were more likely than contrasting pale moths to escape the attention of predators.

Much as the Industrial Revolution changed the environment for moths, farming changed the environment for plants. A tilled, fertilized, watered, weeded garden provides growing conditions very different from those on a dry, unfertilized hillside. Many changes of plants under domestication resulted from such changes in conditions and hence in the favored types of individuals. For example, when a farmer sows seeds densely in a garden, there is intense competition among the seeds. Big seeds that can take advantage of the good conditions to grow quickly will now be favored over small seeds that were previously favored on dry, unfertilized hillsides where seeds were sparser and competition less intense. Such increased competition among plants themselves made a major contribution to larger seed size and to many other changes developing during the transformation of wild plants into ancient crops.

WHAT ACCOUNTS FOR the great differences among plants in ease of domestication, such that some species were domesticated long ago and others not until the Middle Ages, whereas still other wild plants have proved immune to all our activities? We can deduce many of the answers by examining the well-established sequence in which various crops developed in Southwest Asia's Fertile Crescent.

It turns out that the earliest Fertile Crescent crops, such as the wheat and barley and peas domesticated around 10,000 years ago, arose from wild ancestors offering many advantages. They were already edible and gave high yields in the wild. They were easily grown, merely by being sown or planted. They grew quickly and could be harvested within a few months of sowing, a big advantage for incipient farmers still on the borderline between nomadic hunters and settled villagers. They could be readily stored, unlike many later crops such as strawberries and lettuce. They were mostly self-pollinating: that is, the crop varieties could pollinate themselves and pass on their own desirable genes unchanged, instead of having to hybridize with other varieties less useful to humans. Finally, their wild ancestors required very little genetic change to be converted into crops—for instance, in wheat, just the mutations for nonshattering stalks and uniform quick germination.

A next stage of crop development included the first fruit and nut trees, domesticated around 4000 B.C. They comprised olives, figs, dates, pomegranates, and grapes. Compared with cereals and legumes, they had the drawback of not starting to yield food until at least three years after planting, and not reaching full production until after as much as a decade. Thus, growing these crops was possible only for people already fully committed to the settled village life. However, these early fruit and nut trees were still the easiest such crops to cultivate. Unlike later tree domesticates, they could be grown directly by being planted as cuttings or even seeds. Cuttings have the advantage that, once ancient farmers had found or developed a productive tree, they could be sure that all its descendants would remain identical to it.

A third stage involved fruit trees that proved much harder to cultivate, including apples, pears, plums, and cherries. These trees cannot be grown from cuttings. It's also a waste of effort to grow them from seed, since the offspring even of an outstanding individual tree of those species are highly variable and mostly yield worthless fruit. Instead, those trees must be grown by the difficult technique of grafting, developed in China long after the beginnings of agriculture. Not only is grafting hard work even once you know the principle, but the principle itself could have been discovered only through conscious experimentation. The invention of grafting was hardly just a matter of some nomad relieving herself at a latrine and returning later to be pleasantly surprised by the resulting crop of fine fruit.

Many of these late-stage fruit trees posed a further problem in that their wild progenitors were the opposite of self-pollinating. They had to be cross-pollinated by another plant belonging to a genetically different variety of their species. Hence early farmers either had to find mutant trees not requiring cross-pollination, or had consciously to plant genetically different varieties or else male and female individuals nearby in the same orchard. All those problems delayed the domestication of apples, pears, plums, and cherries until around classical times. At about the same time, though, another group of late domesticates arose with much less effort, as wild plants that established themselves initially as weeds in fields of intentionally cultivated crops. Crops starting out as weeds included rye and oats, turnips and radishes, beets and leeks, and lettuce.

ALTHOUGH THE DETAILED sequence that I've just described applies to the Fertile Crescent, partly similar sequences also appeared elsewhere in the world. In particular, the Fertile Crescent's wheat and barley exemplify the class of crops termed cereals or grains (members of the grass family), while Fertile Crescent peas and lentils exemplify pulses (members of the legume family, which includes beans). Cereal crops have the virtues of being fast growing, high in carbohydrates, and yielding up to a ton of edible food per hectare cultivated. As a result, cereals today account for over half of all calories consumed by humans and include five of the modern world's 12 leading crops (wheat, corn, rice, barley, and sorghum). Many cereal crops are low in protein, but that deficit is made up by pulses, which are often 25 percent protein (38 percent in the case of soybeans). Cereals and pulses together thus provide many of the ingredients of a balanced diet.

As Table 7.1 (next page) summarizes, the domestication of local cereal / pulse combinations launched food production in many areas. The most familiar examples are the combination of wheat and barley with peas and lentils in the Fertile Crescent, the combination of corn with several bean species in Mesoamerica, and the combination of rice and millets with soybeans and other beans in China. Less well known are Africa's combination of sorghum, African rice, and pearl millet with cowpeas and groundnuts, and the Andes' combination of the noncereal grain quinoa with several bean species.

Table 7.1 also shows that the Fertile Crescent's early domestication of flax for fiber was paralleled elsewhere. Hemp, four cotton species, yucca, and agave variously furnished fiber for rope and woven clothing in China,

TABLE 7.1. **Examples of Early Major Crop Types around the Ancient World**

Area	*Crop Type*				
	Cereals, Other Grasses	Pulses	Fiber	Roots, Tubers	Melons
Fertile Crescent	emmer wheat, einkorn wheat, barley	pea, lentil, chickpea	flax	—	muskmelon
China	foxtail millet, broomcorn millet, rice	soybean, adzuki bean, mung bean	hemp	—	[muskmelon]
Mesoamerica	corn	common bean, tepary bean, scarlet runner bean	cotton *(G. hirsutum)*, yucca, agave	jicama	squashes *(C. pepo*, etc.)
Andes, Amazonia	quinoa, [corn]	lima bean, common bean, peanut	cotton *(G. barbadense)*	manioc, sweet potato, potato, oca	squashes (*C. maxima*, etc.)
West Africa and Sahel	sorghum, pearl millet, African rice	cowpea, groundnut	cotton *G. herbaceum)*	African yams	watermelon, bottle gourd
India	[wheat, barley, rice, sorghum, millets]	hyacinth bean, black gram, green gram	cotton *(G. arboreum)*, flax	—	cucumber
Ethiopia	teff, finger millet, [wheat, barley]	[pea, lentil]	[flax]	—	—
Eastern United States	maygrass, little barley, knotweed, goosefoot	—	—	Jerusalem artichoke	squash *(C. pepo)*
New Guinea	sugar cane	—	—	yams, taro	—

The table gives major crops, of five crop classes, from early agricultural sites in various parts of the world. Square brackets enclose names of crops first domesticated elsewhere; names not enclosed in brackets refer to local domesticates. Omitted are crops that arrived or became important only later, such as bananas in Africa, corn and beans in the eastern United States, and sweet potato in New Guinea. Cottons are four species of the genus *Gossypium*, each species being native to a particular part of the world; squashes are five species of the genus *Cucurbita*. Note that cereals, pulses, and fiber crops launched agriculture in most areas, but that root and tuber crops and melons were of early importance in only some areas.

Mesoamerica, India, Ethiopia, sub-Saharan Africa, and South America, supplemented in several of those areas by wool from domestic animals. Of the centers of early food production, only the eastern United States and New Guinea remained without a fiber crop.

Alongside these parallels, there were also some major differences in food production systems around the world. One is that agriculture in much of the Old World came to involve broadcast seeding and monoculture fields, and eventually plowing. That is, seeds were sown by being thrown in handfuls, resulting in a whole field devoted to a single crop. Once cows, horses, and other large mammals were domesticated, they were hitched to plows, and fields were tilled by animal power. In the New World, however, no animal was ever domesticated that could be hitched to a plow. Instead, fields were always tilled by hand-held sticks or hoes, and seeds were planted individually by hand and not scattered as whole handfuls. Most New World fields thus came to be mixed gardens of many crops planted together, rather than monoculture.

Another major difference among agricultural systems involved the main sources of calories and carbohydrates. As we have seen, these were cereals in many areas. In other areas, though, that role of cereals was taken over or shared by roots and tubers, which were of negligible importance in the ancient Fertile Crescent and China. Manioc (alias cassava) and sweet potato became staples in tropical South America, potato and oca in the Andes, African yams in Africa, and Indo-Pacific yams and taro in Southeast Asia and New Guinea. Tree crops, notably bananas and breadfruit, also furnished carbohydrate-rich staples in Southeast Asia and New Guinea.

THUS, BY ROMAN times, almost all of today's leading crops were being cultivated somewhere in the world. Just as we shall see for domestic animals too (Chapter 9), ancient hunter-gatherers were intimately familiar with local wild plants, and ancient farmers evidently discovered and domesticated almost all of those worth domesticating. Of course, medieval monks did begin to cultivate strawberries and raspberries, and modern plant breeders are still improving ancient crops and have added new minor crops, notably some berries (like blueberries, cranberries, and kiwifruit) and nuts (macadamias, pecans, and cashews). But these few modern additions have remained of modest importance compared with ancient staples like wheat, corn, and rice.

Still, our list of triumphs lacks many wild plants that, despite their value as food, we never succeeded in domesticating. Notable among these failures of ours are oak trees, whose acorns were a staple food of Native Americans in California and the eastern United States as well as a fallback food for European peasants in famine times of crop failure. Acorns are nutritionally valuable, being rich in starch and oil. Like many otherwise edible wild foods, most acorns do contain bitter tannins, but acorn lovers learned to deal with tannins in the same way that they dealt with bitter chemicals in almonds and other wild plants: either by grinding and leaching the acorns to remove the tannins, or by harvesting acorns from the occasional mutant individual oak tree low in tannins.

Why have we failed to domesticate such a prized food source as acorns? Why did we take so long to domesticate strawberries and raspberries? What is it about those plants that kept their domestication beyond the reach of ancient farmers capable of mastering such difficult techniques as grafting?

It turns out that oak trees have three strikes against them. First, their slow growth would exhaust the patience of most farmers. Sown wheat yields a crop within a few months; a planted almond grows into a nut-bearing tree in three or four years; but a planted acorn may not become productive for a decade or more. Second, oak trees evolved to make nuts of a size and taste suitable for squirrels, which we've all seen burying, digging up, and eating acorns. Oaks grow from the occasional acorn that a squirrel forgets to dig up. With billions of squirrels each spreading hundreds of acorns every year to virtually any spot suitable for oak trees to grow, we humans didn't stand a chance of selecting oaks for the acorns that *we* wanted. Those same problems of slow growth and fast squirrels probably also explain why beech and hickory trees, heavily exploited as wild trees for their nuts by Europeans and Native Americans, respectively, were also not domesticated.

Finally, perhaps the most important difference between almonds and acorns is that bitterness is controlled by a single dominant gene in almonds but appears to be controlled by many genes in oaks. If ancient farmers planted almonds or acorns from the occasional nonbitter mutant tree, the laws of genetics dictate that half of the nuts from the resulting tree growing up would also be nonbitter in the case of almonds, but almost all would still be bitter in the case of oaks. That alone would kill the enthusiasm of any would-be acorn farmer who had defeated the squirrels and remained patient.

As for strawberries and raspberries, we had similar trouble competing with thrushes and other berry-loving birds. Yes, the Romans did tend wild strawberries in their gardens. But with billions of European thrushes defecating wild strawberry seeds in every possible place (including Roman gardens), strawberries remained the little berries that thrushes wanted, not the big berries that humans wanted. Only with the recent development of protective nets and greenhouses were we finally able to defeat the thrushes, and to redesign strawberries and raspberries according to our own standards.

WE'VE THUS SEEN that the difference between gigantic supermarket strawberries and tiny wild ones is just one example of the various features distinguishing cultivated plants from their wild ancestors. Those differences arose initially from natural variation among the wild plants themselves. Some of it, such as the variation in berry size or in nut bitterness, would have been readily noticed by ancient farmers. Other variation, such as that in seed dispersal mechanisms or seed dormancy, would have gone unrecognized by humans before the rise of modern botany. But whether or not the selection of wild edible plants by ancient hikers relied on conscious or unconscious criteria, the resulting evolution of wild plants into crops was at first an unconscious process. It followed inevitably from our *selecting* among wild plant individuals, and from competition among plant individuals in gardens favoring individuals different from those favored in the wild.

That's why Darwin, in his great book *On the Origin of Species,* didn't start with an account of natural selection. His first chapter is instead a lengthy account of how our domesticated plants and animals arose through artificial selection by humans. Rather than discussing the Galápagos Island birds that we usually associate with him, Darwin began by discussing—how farmers develop varieties of gooseberries! He wrote, "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." Those principles of crop development by artificial selection still serve as our most understandable model of the origin of species by natural selection.

CHAPTER 8

APPLES OR INDIANS

WE HAVE JUST SEEN HOW PEOPLES OF SOME REGIONS began to cultivate wild plant species, a step with momentous unforeseen consequences for their lifestyle and their descendants' place in history. Let us now return to our questions: Why did agriculture never arise independently in some fertile and highly suitable areas, such as California, Europe, temperate Australia, and subequatorial Africa? Why, among the areas where agriculture did arise independently, did it develop much earlier in some than in others?

Two contrasting explanations suggest themselves: problems with the local people, or problems with the locally available wild plants. On the one hand, perhaps almost any well-watered temperate or tropical area of the globe offers enough species of wild plants suitable for domestication. In that case, the explanation for agriculture's failure to develop in some of those areas would lie with cultural characteristics of their peoples. On the other hand, perhaps at least some humans in any large area of the globe would have been receptive to the experimentation that led to domestication. Only the lack of suitable wild plants might then explain why food production did not evolve in some areas.

As we shall see in the next chapter, the corresponding problem for domestication of big wild mammals proves easier to solve, because there