4
Grains

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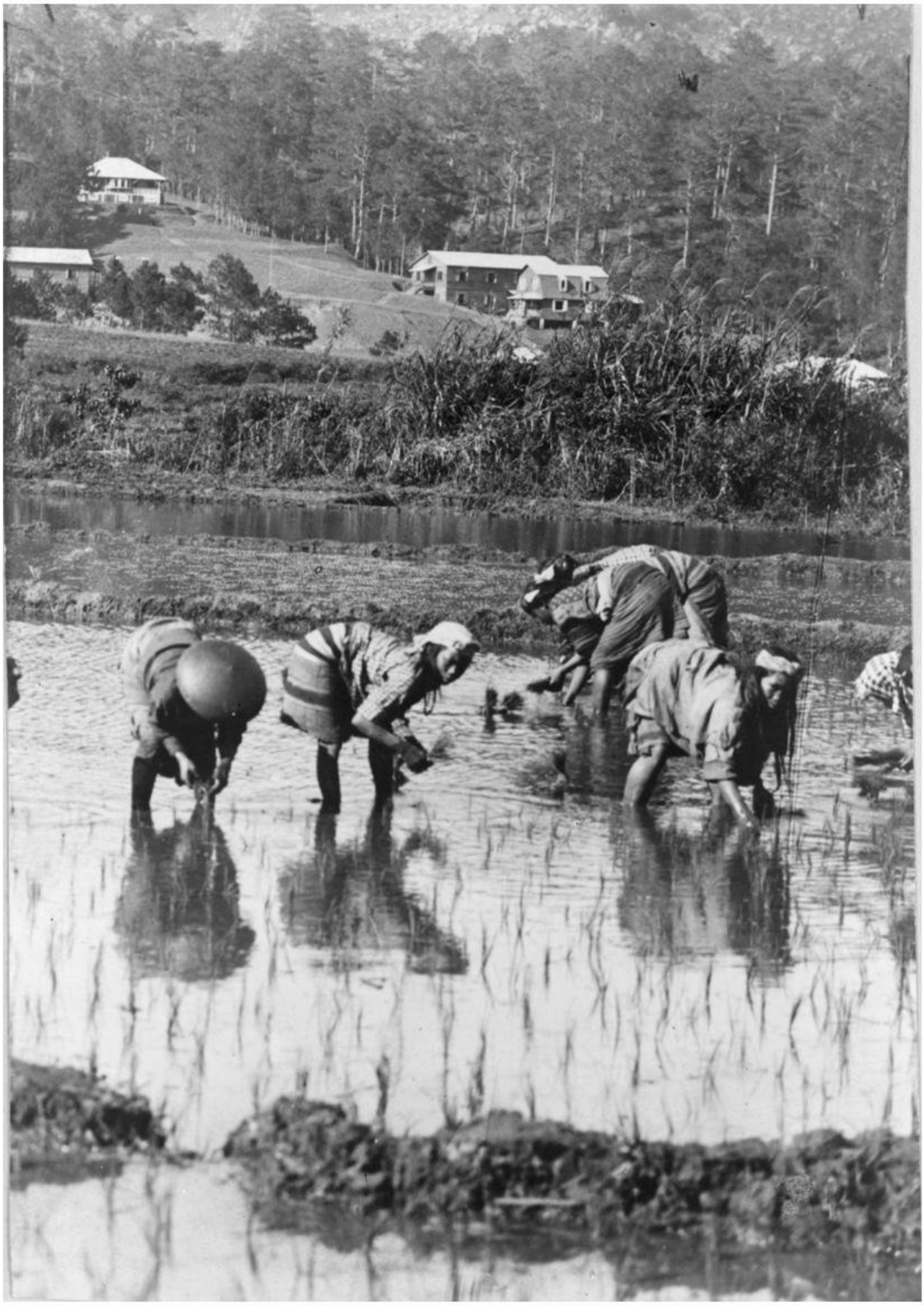
Grains are the edible, starchy seeds (strictly, *caryopses*) of grasses. They account for over half of the world's food energy, or even more counting grain consumed indirectly as animal food. Cereals are the dominant food for a number of reasons. Diverse members of the grass family (Poaceae) will grow in virtually all the world's human habitats. Cereals are not only easily grown by farmers, but are also very nutritious. The cereal grain consists of the starchy endosperm; the oil-, vitamin-, and mineral-rich aleurone layer surrounding it; and the outermost, fibrous layers of bran. The embryo (germ) is also rich in oil. The grain has excellent keeping qualities prior to milling, enhanced in many species by the closely-fitting or attached husk (in some species the glumes, in others the lemma and palea). Grains generally lack the toxins so prevalent in the pulses, and nutritional deficiencies of species such as corn (maize) and sorghum can be mitigated through fermentation. Malting—the deliberate sprouting then killing of grains—results in the conversion of starch to sugar and is another powerful tool for enhancing the nutritional value of grains.

The domesticated cereals are often classified as temperate or tropical. Many of the temperate cereals, which fail to thrive at high temperatures, can be grown in the tropics, but only at high altitudes. Various of the tropical cereals, including corn, sorghum, and the millets, have C4 metabolism, based on a distinctive type of leaf anatomy and a modified photosynthetic pathway, which is well adapted to the high light levels of the tropics. Some tropical cereals, including sorghum and corn, are also viable crops in warmer temperate areas. Almost all cereals are annuals, sown in the autumn or spring and harvested in the summer. The leaves and stems of cereals are often as important as the grain, for animal feed, fuel, and construction materials such as thatch.

Rice, corn, and wheat are by far the most important of any crops, each accounting for about 600 million metric tons of grain each year (total world cereal production is 2000 million metric tons). These are the crops that underpinned the "green revolution" of the 1960s. New cultivars of cereals that responded well to increased inputs of water and fertilizer were developed. As a result, global agricultural production outpaced the doubling of the world's population that occurred between 1950 and 1990. The less important species of cereals are now attracting increased interest. Similar efforts applied to arid-land crops such as sorghum may benefit areas bypassed by the green revolution. Minor crops are important for other reasons; they are often well-adapted to cold or dry areas unsuitable for the major crops, offering a means of subsistence for farmers who would otherwise



Rice planting, Philippine Islands, ca.1890. Library of Congress, Prints & Photographs Division LC-USZ62-113571.

migrate to cities. Minor cereals frequently have important local culinary or religious significance, representing cultural diversity that, like biological diversity, should be preserved.

Domesticated cereals differ from their wild ancestors in a number of features (see Table 2 in Conservation of Crop Genetic Resources). In particular, grains are usually larger in domesticated forms, and the ears retain the grain until harvest, rather than shattering and releasing the grain, as in wild cereals. The different parts of the cereal ear usually survive charring or desiccation and are thus often well-preserved in archaeological deposits. By studying characteristics relating to grain size and dissemination, the domestication status of cereals can usually be established. In the Near East intensive archaeological and genetic studies have resulted in a good understanding of the domestication of wheat, barley, and rye (see Origins and Spread of Agriculture).

In other areas, such as Mesoamerica, south and east Asia, and Africa, both the archaeological records and our knowledge of the wild ancestors of cereals are poor. The problem is greatest in Africa, explaining why many cereals of African origin have their earliest archaeological records outside Africa, for example in the better-explored Indian subcontinent. A similar problem exists in Mexico, where no plant remains have been collected from early farming sites in the mountainous area where teosinte, the wild ancestor of corn, grows. The earliest corn yet found, from valleys outside this area, must substantially postdate the time of domestication.

All the species covered in this chapter belong to the grass family (Poaceae), except for three genera classified as pseudocereals: amaranths, buckwheat, and quinoa. These have small starchy seeds and hence are often considered as grains in culinary and agricultural terms.

Grass based cereals (Poaceae)

Archaeological evidence shows that in some areas, such as the Near East, the collection of wild grains for food ceased soon after the beginning of farming. Grains could be more easily obtained by cultivating domesticated cereals than by gathering from the wild. In other parts of the world, wild grains have continued to be important foods to the current day. This is mainly the case in areas too wet or too dry for farming, such as sea- and lakeshores and desert margins. In these areas wild grasses are still important resources, sometimes for hunter-gatherers, but more often as a supplementary resource for farmers. A wide range of grasses is used, often harvested from mixed stands of different species. Examples are given here of grasses harvested in the past, particularly in Europe (where their use has long since ceased) but also in North America, Australia, and sub-Saharan Africa, where some are still major food plants.

Crabgrass *Digitaria sanguinalis*

Crabgrass has a long history of collection as a wild grain in Europe, and came late to cultivation. It was domesticated in eastern Europe in the Middle Ages, and grown by Slavic peoples in a belt stretching from eastern Germany to the Ukraine for use in porridge and soups. However, its cultivation had ceased by the 20th century. Wild *Digitaria* species are today more important as forage grasses or for erosion control.

Floating sweetgrass *Glyceria fluitans*

This is a wild perennial grass of wet or marshy habitats. Known as manna grass or sugar grass, on account of its slightly sweet grains, it was extensively harvested in central Europe and Sweden up until the mid-19th century. The small grains were appreciated for their sweet taste and traded as far away as England. For consumption, the grains were pounded in a wooden mortar and eaten as gruel.

Lyme-grass *Leymus arenarius*

Lyme-grass was an important wild grain in Iceland from at least the 12th century, its use continuing until the mid-20th century. This perennial grass grows on the sandy shores of Iceland's southern coast, and was harvested with small sickles and threshed by lashing the sheaves against a wall.

After parching in a kiln, the resulting brittle florets were dehusked by treading in a cask. The grains were then ground, mixed with milk or whey, and consumed as an unbaked dough. Such wild resources were important until very recently because Iceland is too cold for most crops.

Maygrass *Phalaris caroliniana*

An annual grass of the southeast United States, maygrass has small seeds that are often found on prehistoric sites in the region, from 4500 ^{14}C years ago. Although there is only one ethnographic report of maygrass use by native Americans, its use as human food in the past is shown by its occurrence in many prehistoric coprolites (desiccated human feces) from cave sites in Kentucky. Prehistoric finds of maygrass occur well north of its current distribution, for example in Kentucky and Tennessee, suggesting that although never domesticated, maygrass might have been cultivated.

Panic grasses *Panicum* spp.

Although best known for the domesticated broomcorn millet (*P. miliaceum*, see later separate entry), the 500 species of the genus *Panicum* include several important wild cereals in dry areas of the southwest United States, the interior of Australia, and sub-Saharan Africa.

In the Sonoran desert of the American Southwest, seed was collected from wild populations of *Panicum sonorum* and *P. hirticaule* growing on the banks of the Colorado River. A large-seeded domesticated form of *P. sonorum,* which was sown in early summer on moist soils as the river subsided, also existed, although it was nearly extinct by the late 20th century. The grains were parched to remove the husk, then the seeds were ground to flour and used as sun-dried cakes. In the arid Great Basin, east of the Sierra Nevada mountains of California, a wide range of wild grasses was harvested, including species of *Panicum*, *Eragrostis* (see Teff later) and *Oryzopsis*. Many of these were sown, and the Owens Valley Paiute of the Great Basin used irrigation to enhance the yields of wild stands. Seeds were harvested by beating the grain into baskets and then grinding the seeds to flour.

In the dry interior of Australia, a similar range of wild grasses, including species of *Panicum*, *Setaria* (see Foxtail millet later), and *Eragrostis*, were recorded as being harvested by hunter-gatherers in the 19th century by hand-stripping of seeds or uprooting of whole plants. Vast ricks of uprooted grasses were observed along the Darling River. The seeds were wet-ground on a millstone, then formed into a cake for cooking.

Harvesting of wild grains is increasingly uncommon in North America (save for wild rice) and Australia, but in the Sahara desert and sub-Saharan Africa, large-scale use of wild grasses by farming communities is still an important food resource. *Panicum turgidum* (merkba, afezu) is used by the Tuareg peoples of southern Algeria. The grass is protected from grazing until after the grain is harvested; the seeds are used for porridge. *Stipagrostis pungens* (drinn, tessiya, tullult) and *Cenchrus biflorus* (kram-kram) are also used in the desert zone. South of the Sahara, different grasses are harvested from seasonally flooded lakes and swamps of west Africa. These include wild rice, *Oryza barthii,* and *O. longistaminata*, *Paspalum scrobiculatum* var. *commersonii*, and *Echinochloa stagnina*. In the savanna zone south of Lake Chad, wild grass grains are known as kreb, and derive from a mixture of grasses dominated by *Panicum* and *Eragrostis*.

See: Origins and Spread of Agriculture, p. 17

Wild rice *Zizania palustris*

Wild rice is an aquatic grass native to the Great Lakes region of eastern North America, entirely unrelated to the Asian and African rices (*Oryza,* see Rice later). It has been harvested for millennia by local native American peoples, including the Ojibway, Cree, Menomini, and Huron. It is traditionally harvested by flail-beating the grains into canoes. The harvested grain was dried,

often over a fire, then dehusked by trampling. The grains were cooked in soups or boiled with fish, corn, or meat.

Cultivation of wild rice in diked fields began about 1950. In the 1960s wild rice was domesticated by plant breeders who selected shatter-resistant types that were less likely to shed grain before harvest. Domesticated wild rice is harvested by combine harvesters after the field is drained. Wild rice is an annual grass, but minimal resowing is required as even shatter-resistant cultivars shed some grain. Today about one-tenth of the harvest is from natural stands; the remainder is from fields, mainly in Minnesota and northern California. Of the three other species in the genus *Zizania*, *Z. aquatica* and *Z. texana* are small-seeded forms not harvested for food, and the Chinese species *Z. latifolia* is gathered as a wild grain in Manchuria.

See: The Hunter-Gatherers, pp. 10–12

Temperate cereals

Barley *Hordeum vulgare*

Although mainly grown today for animal feed and for brewing, barley was an important cereal food in the past. Even today, naked barley (a hull-less variety that is easy to process) is still a staple cereal in the Himalayas. The importance of barley in such high-altitude areas reflects barley's hardiness; like rye, it is a more dependable crop than wheat in areas that are particularly dry, wet, or cold, and in areas with soils affected by salinity.

The wild ancestor of barley is *H. spontaneum*, a large-seeded barley that grows alongside wild wheat in the Fertile Crescent of the Near East (see Figure 1 in Origins and Spread of Agriculture). Both wild barley and the first domesticated barley were similar in appearance, with two rows of grain on the ear, and both had hulled grains, in which the husk (lemma and palea) adheres to the grain. This husk is rich in silica and must be removed by pounding before consumption for food. In naked forms, the lemma and palea do not adhere to the grain and are easily removed by threshing.

Domesticated barley is abundant at Near Eastern archaeological sites from 9500 ^{14}C years ago, and the crop spread to Europe, Egypt, and south Asia from about 8000 ^{14}C years ago, with the other Neolithic crops of the Fertile Crescent. Six-rowed forms of barley, with three fertile spikelets on each node of the ear, appear at about 8000 ^{14}C years ago. Today barley is grown in most areas for animal feed, but the abundance of barley in archaeological deposits, often in kitchens, shows that it was an important human food, probably even outranking wheat, and was used for both porridge and bread. It is perhaps only since medieval times that barley's role as a staple food has disappeared in most regions. Food use of barley appears to have declined first in warmer regions such as classical Rome, and to have survived longest in northern, colder areas such as Scandinavia. In the Orkney and Shetland Isles, bere barley—distinctive six-row hulled barley—is still grown for the production of bannocks, a kind of soft flat bread.

Although naked forms of barley make sporadic appearances in the Fertile Crescent and Europe, it is only in East Asia that they became important foods. Although naked barley does not need dehusking prior to consumption, hulled barley has higher yields, and this may explain why it has stayed the dominant form.

See: Origins and Spread of Agriculture, pp. 14–17; Caffeine, Alcohol, and Sweeteners, p. 182

Canary grass *Phalaris canariensis*

Widely cultivated for bird feed, canary grass is a rare crop in Italy and, in the Canary Isles, where it is one of a number of cereals used to make a local cereal dish known as *gofio*. *Phalaris caroliniana* (maygrass, as described earlier) was probably cultivated as a cereal in prehistoric times in eastern North America.

Common millet, broomcorn millet *Panicum miliaceum*

Both the wild ancestor and the location of domestication of broomcorn millet are unknown, but it first appears as a crop in both Transcaucasia and China about 6000 ^{14}C years ago, suggesting that it may have been domesticated independently in each area. Like foxtail millet, it is a summer crop, sown in late spring and harvested in late summer. The grains are eaten whole after boiling, or ground into flour for porridge or bread. Broomcorn millet is an important bird feed in many countries. Sama (*P. sumatrense*) was domesticated in the Indian subcontinent and is present at Harappan sites from 3000 BC. It is cultivated in south Asia, particularly in the eastern Ghats of India, and eaten as whole grains or as bread.

See: Origins and Spread of Agriculture, p. 17

Foxtail millet *Setaria italica*

This millet of temperate regions was domesticated from its wild ancestor, *S. viridis*, in eastern Asia about 7000 ^{14}C years ago. Foxtail millet was a staple food in the Neolithic period in northern China, in contrast to the dominance of rice in the south. Genetic evidence suggests that foxtail millet may have been independently domesticated in central Asia and China. The major areas of production today are China and India. Foxtail millet is eaten as whole, boiled grains, or ground into flour. Like most other millets, it is a summer crop, sown in late spring and harvested after a growing season of as little as forty days. Foxtail millet is increasingly being displaced by broomcorn millet and other cereals. Yellow foxtail millet (*S. pumila*) is an Indian domesticate; it has been cultivated as a minor cereal in India since 2000 BC.

See: Origins and Spread of Agriculture, p. 17

Mango *Bromus mango*

Not to be confused with the tropical fruit, this cereal was cultivated in Chile and Argentina, but was displaced by corn, wheat, and barley after the Spanish Conquest. Cultivation ceased by about 1860. It was a biennial crop so only produced seed in its second year of growth. The Araucani Indians used it as a dual-purpose crop, as forage for grazing animals the first year and for grain the second year. After roasting, grains were ground into flour for bread, or for a fermented drink known as *chicha*.

Oats *Avena sativa*

Oats are descended from *A. sterilis*, a wild oat that spread as a weed of wheat and barley from the Fertile Crescent to Europe. In the wetter, colder conditions of Europe, in which oats thrive, it was domesticated about 3000 years ago, and soon became an important cereal in its own right on the cooler fringes of Europe. In medieval Britain oats were widely grown for bread, biscuits, and malting, but they now hold their importance only in the wetter parts of northern Europe. Oats are still an important food in Scotland, where uses include porridge, oatcakes, and the filling for haggis. Oats have also had an important role since the Roman period as feed for horses. British emigrants introduced oat cultivation to North America in the 17th century, but they have always been a minor cereal outside Europe. Oat bran is rich in a type of dietary fiber that has been shown to reduce cholesterol levels, and this has led to increased interest in its consumption.

Red oat or Turkey oat, *Avena byzantina,* is also descended from *A. sterilis*. Although sometimes considered to be the same species as *A. sativa*, red oats are genetically distinct and have a different distribution including, as the name suggests, Turkey. However, red oats have been largely replaced by *Avena sativa* in recent years.

Four minor cultivated species derived from wild forms of *Avena strigosa* grow in the western Mediterranean. Bristle oat, *A. strigosa*, is a fodder plant in central and northern Europe, still grown

in the Shetland Islands but almost extinct. *A. brevis* and *A. hispanica* are now very rare crops of southwest Europe. *A. nuda* is a naked form of oat that threshes free of the tough husk. It has low yields and is not widely cultivated.

Avena abyssinica is only found in Ethiopia. It grows as a tolerated weed of other cereals, mainly barley, and is now in the course of domestication.

Rye *Secale cereale*

Rye was first domesticated in the Fertile Crescent of the Near East, with the earliest records dating to 8400 ^{14}C years ago, but did not become an established crop until the Bronze Age in Europe, about 3500 years ago. Like oats, rye only became important in the cold, wet conditions of central and northern Europe, in which it grows better than other cereals. It was used for bread and for thatching, and was (and in Turkey, still is) often planted with bread wheat as a mixture or *maslin*. In poor years the increased yield of the hardier rye compensates for the more vulnerable wheat. In western Europe rye was displaced by wheat as a staple cereal in the 18th century, and is now primarily grown for animal feed. Rye breads such as pumpernickel are still important in central Europe.

See: Origins and Spread of Agriculture, p. 16

Triticale × *Triticosecale*

Triticale results from the crossing of macaroni wheat or bread wheat with rye. It was originally a laboratory curiosity, discovered in the 19th century. Intensive breeding programs were carried out in the 1950s, in the hope of developing a new cereal species that would combine the grain quality of wheat and the hardiness of rye. However, problems with grain shriveling and with ergot (a fungus that produces harmful alkaloids) have slowed uptake as a crop. Triticale is grown today for animal feed, mainly in France, Poland, Russia, and Australia.

Wheat *Triticum* spp.

Wheat is by far the most important food grain of temperate regions. Its role in human subsistence is matched by the deep significance of wheat in religion and daily life. Wheat, in the form of bread, is central to Jewish and Christian rites. Although barley was domesticated at the same time, has higher yields, and was the most important cereal in antiquity, wheat has always been more highly valued, probably because of its better taste and more versatile culinary properties.

Papago winnowing wheat, ca.1907. Library of Congress, Prints & Photographs Division, Edward S. Curtis Collection.

The wheats divide into two groups, hulled and free-threshing. On threshing, the ear (spike) of hulled wheats breaks up into individual spikelets, in each of which one to three grains are tightly enclosed by tough husks or hulls (glumes). Before the grains can be consumed, they must be dehusked, traditionally by pounding in a mortar. In contrast, the glumes of free-threshing wheats are light and break away during threshing, releasing the naked grains immediately. Most wheats cultivated today are free-threshing; all wild wheats and many species cultivated in the past were hulled.

The earliest cultivated wheats were hulled forms. Einkorn wheat (*T. monococcum)* and emmer (*T. dicoccum*) were domesticated from wild einkorn (*T. boeoticum*) and wild emmer (*T. dicoccoides*) respectively, in the Fertile Crescent of the Near East. The earliest securely dated finds of domesticated einkorn and emmer are at Neolithic (Pre-Pottery Neolithic B) sites in Syria, Jordan, and southeast Turkey, dating from 9500 to 9200 ^{14}C years ago. Genetic evidence suggests that present-day einkorn and emmer derive from one or two domestications, probably in southeast Turkey. Emmer was the main wheat species grown by early farmers in Europe and the Near East and the only wheat grown in ancient Egypt, where emmer bread and beer were staple foods. Einkorn has always been less important. Because of their ability to thrive on poor soils and to resist fungal diseases, emmer and einkorn are still grown in wet mountainous areas stretching from the Pontic mountains of Turkey to the Carpathian mountains of eastern Europe, and in Italy and Spain. In Italy emmer is known as *farro* and cooked whole with beans or tomatoes to make soup. Einkorn is used as animal feed and for thatching, and in Turkey is favored as a food grain for cracked wheat (bulgur). Unlike emmer and spelt, einkorn has not become a popular health food, and it is in danger of becoming extinct as a crop.

Macaroni wheat (*T. durum*) is the free-threshing form of emmer wheat, with hard, flinty grains. It first appeared in the Near East about 9000 ^{14}C years ago. Macaroni wheat has always been important in Mediterranean areas. Its best-known use is for pasta, a food of uncertain origin, perhaps from the Arab world and not, as often claimed, brought back from China by Marco Polo. In the 19th century the Ukraine became the leading exporter of macaroni wheat for pasta making, but it lost this position to the United States during World War I. Macaroni wheat also makes a delicious bread that is a staple food in Sicily. Rivet wheat (*T. turgidum*) is a closely related species that is well adapted to the cooler conditions of northern Europe. It was popular during the medieval period, but bread wheats proved better adapted to the threshing machines introduced in the 19th century, and were better suited to industrialized baking. Rivet wheat has notably soft, floury grains, and produced a good bread-making flour that was mixed with flour from rye and bread wheat for daily baking. Miracle wheat (*T. turgidum* var. *pseudocervinum*) is a form of rivet wheat with branched ears, first recorded by the Roman author Pliny some 2000 years ago. Extravagant claims are often made for its yield but, sadly, miracle wheat has yields of grain well below those of ordinary wheats. It is often claimed that miracle wheat or mummy wheat derives from grains found in ancient tombs and subsequently germinated. However, except when stored at very low temperatures, cereal grains lose their ability to germinate within a few years or, at best, decades.

Spelt (*T. spelta*) is a hulled wheat that became widely cultivated much later than most other wheats. Genetic evidence shows that it is the result of the hybridization of emmer wheat and a wild goatgrass, *Aegilops tauschii*, some 8000 ^{14}C years ago near the Caspian Sea. However, spelt never became part of the Near Eastern crop complex that spread to Europe through the Balkans. Instead, it suddenly appears as an important crop in central Europe about 4000 years ago. Spelt displaced emmer as the major wheat of antiquity in Europe, before being displaced in turn by free-threshing wheat. Spelt has continued in local cultivation in Germany and Switzerland, where it is much appreciated for use in baking bread known as *Dinkelbrot*. Spelt grains are widely sold in health food shops in Europe and North America, and cultivation in western Europe continues to expand.

Spelt is often and mistakenly thought to have been grown in Pharaonic Egypt or the ancient Near East; this error results from confusion with emmer wheat, which was widely grown in both areas in antiquity.

Bread wheat (*T. aestivum*) is free-threshing and closely related to spelt. As with spelt, genes contributed from goatgrass (*Aegilops*) give bread wheat greater cold hardiness than most wheats, and it is cultivated throughout the world's temperate regions. Bread wheat is by far the most important wheat species today. Wheat first reached North America with Spanish missions in the 16th century, but North America's role as a major exporter of grain dates from the colonization of the prairies in the 1870s. As grain exports from Russia ceased in the First World War, grain production in Kansas doubled. Worldwide, bread wheat has proved well adapted to modern industrial baking, and has displaced many of the other wheat, barley, and rye species that were once commonly used for bread making, particularly in Europe. Compact wheats (*T. compactum*, in India *T. sphaerococcum*) are closely related, but have a much more compact ear, with spikelets packed closer together.

Modern wheat varieties have short stems, the result of *RHt* dwarfing genes that reduce the plant's sensitivity to gibberellic acid, a plant hormone that lengthens cells. *RHt* genes were introduced to modern wheat varieties in the 1960s from Norin cultivars of wheat grown in Japan. Short stems are important because the application of high levels of chemical fertilizers would otherwise cause the stems to grow too high, resulting in lodging (collapse of the stems). Stem heights are also even, important for modern harvesting techniques.

See: Origins and Spread of Agriculture, pp. 16 and 17

Tropical cereals

Adlay *Coix lacryma-jobi*

This species exists in two forms, Job's tears and Adlay. Job's tears have shiny bracts, and are often used as beads in botanical jewellery. Adlay (var. *ma-yuen*) has papery bracts and starchy grains, and is grown on a small scale as a food grain in east and southeast Asia. The grains are eaten whole in soup, or ground into flour and eaten as porridge or cakes. In Nagaland, northeast India, and in some parts of southeast Asia, adlay is used for brewing local beers. The fruits have a variety of traditional medicinal uses, including reputed anticancer properties. Cultivation is decreasing as adlay is replaced by rice and corn. The date and region of domestication are unknown, but adlay is found at archaeological sites in northeast India from about 1000 BC. The wild ancestor (var. *lacryma-jobi*), native to tropical Asia, is thick-shelled; the thin-shelled edible form evolved under domestication. Unlike most other cereals, adlay plants are cultivated on a small scale, often in home gardens. Each plant bears a large number of ears, which mature at different times; these are hand-picked as they mature.

See: Materials, pp. 343–344

Browntop millet *Brachiaria ramosa*

This rare millet is now only cultivated in a few dry areas of South India, but it is a good example of crop evolution in action. Three forms illustrate the transition from wild plant to crop: the wild form retains fully wild characteristics; a weedy form is grown as fodder and is harvested for grain in drought years; and the fully domesticated type, taller and with larger and non-shattering ears, is cultivated in pure stands. The grain is consumed as boiled whole grains, porridge, or unleavened bread. Today the browntop millet is threatened with extinction as farmers adopt new commercial crops, and food habits change.

See: Origins and Spread of Agriculture, p. 19

Corn, maize *Zea mays*

No other cereal has spread so widely or been used in such diverse manners as corn. In its homeland of Mesoamerica corn is the staple food, usually eaten as griddle-cooked *tortilla* bread. In North America, traditional corn landraces are still widely grown by native American peoples of the Southwest, but corn's greatest importance today is as an agro-industrial crop, mostly used for industrial starch, alcohol production, corn syrup, and animal feed. Corn was taken by the Portuguese in the 16th century to Africa and rapidly became established as a staple food over much of the continent. Today corn ranks second in world production behind rice. With its high yields, corn is likely to increase in importance in warm parts of the world.

The domestication of corn has long been controversial. The flowers on the cob of modern-day corn are arranged in a distinctive fashion, very different from that of its wild ancestor, teosinte (subsp. *parviglumis*). The female flowers are arranged in rows, which are pollinated through the long, thin styles (the "silk") that can be seen emerging from the cob. The female flowers mature into the corn grains that we eat. The male flowers grow together on the tassel at the tip of the corn stem, well placed to shower pollen onto the female cobs below. In contrast, teosinte has numerous much smaller cobs, with just two rows of grain, and a male inflorescence at the end of each cob. These differences led botanists to increasingly complex explanations of corn domestication, involving crossing of different species, or an extinct wild ancestor. However, recent studies of DNA have shown that teosinte is the only ancestor of corn. Teosinte grows today as a wild plant in river valleys of southern and western Mexico, and this area is believed to be where corn was first domesticated.

The earliest domesticated corn cobs have been found at archaeological sites in the Tehuacán and Oaxaca valleys of southern Mexico, dating to 6000 to 5000 ^{14}C years ago. Similar cobs are found on a primitive form of popcorn cultivated today on a small scale in Argentina. With its small cobs and branched stems, this variety is intermediate in appearance between teosinte and modern corn. By about 3000 years ago corn had spread from Mexico with early farmers, south to the Andes and north to eastern North America. Corn arrived in Europe and Asia after Columbus reached the Americas in 1492, and spread rapidly. Although many claims have been made for pre-Columbian dispersal of corn in the Old World, these are firmly contradicted by the complete absence of corn in the Old World archaeological record before 1492.

An astonishing range of landraces of corn has evolved in response to selection for culinary attributes, particularly in the southwest United States. Flour corn has large, soft, starchy grains, with blue, pink, or white flour used for cornmeal. Sweet corn is used for flour (*pinole*) or eaten on the cob. A genetic defect in metabolism prevents the sugars in the kernel from being fully converted to starch, hence the sweet taste. Popcorn has flinty, hard kernels that explode on toasting. The chemistry of popcorn is still poorly understood, but it appears that the high protein content of popcorn grains binds together the starch particles. When heated, the grain thus resists expansion, until the pressure of heated water vapor inside the grain forces it to explode.

In Mesoamerica the process of nixtamalization developed about 1500 BC, and is still widely practiced both in villages and in industrial food production. Corn grains are soaked, then cooked with lime or wood ash. This process both enables the husk (pericarp) of the grain to be easily removed, and improves the availability of a B vitamin, niacin, in the grain. Niacin deficiency leads to the disease pellagra, with symptoms including skin lesions and mental confusion. Pellagra was widespread in areas such as the southern United States, in which the diet of poor cotton shareholders depended heavily on corn, and the disease still occurs in parts of south Africa, Egypt, and India. Corn is also particularly deficient in two essential amino acids, lysine, and tryptophan. In the Americas *Phaseolus* beans complement corn by meeting this deficiency; elsewhere other pulses take the same role.

See: Age of Industrialization and Agro-industry, pp. 357–359; Origins and Spread of Agriculture, p. 21

Fonio *Digitaria* spp.

White fonio (*Digitaria exilis*) is the most important of a diverse group of wild and domesticated *Digitaria* species that are harvested in the savannas of west Africa. Fonio has continued to be important locally because it is both nutritious and one of the world's fastest growing cereals, reaching maturity in as little as six to eight weeks. Fonio is a crop that can be relied on in semi-arid areas with poor soils, where rains are brief and unreliable. The grains are used in porridge and couscous, for bread, and for beer. Black fonio (*Digitaria iburua*) is a similar crop grown in Nigeria, Togo, and Benin. Raishan (*D. compacta*) is a minor cereal, only grown in the Khasi hills of northeast India, with glutinous flour used to make bread or porridge.

Finger millet *Eleusine coracana*

Finger millet is an important tropical cereal in eastern and southern Africa and in India. It was domesticated in east Africa from *E. africana*, which grows in Ethiopia and Uganda. Claims of identifications of prehistoric seeds of finger millet from India and Africa are poorly documented, but it does appear to be one of the cereals, along with sorghum and pearl millet, that reached India in the second millennium BC. So far, the earliest certain record from Africa is from Axum, Ethiopia, dating to 600 AD.

Finger millet is not as drought tolerant as pearl millet and competes with corn for the best agricultural land in Africa. The grain is ground and made into porridge and a local bread, and it is also malted for beer. As the grain can be stored for long periods, it is an important crop during times of famine. Rich in calcium and iron, it is often recommended as a healthy food for pregnant women, children, and sick people. In recent years cultivation of finger millet has declined in its African heartland, causing concern that a valuable crop may be lost through lack of investment in plant-breeding programs. In India finger millet (known as ragi) has increased in importance as a dryland crop.

Guinea millet *Urochloa deflexa*

This millet is cultivated locally on the Fouta Djalon plateau of Guinea, west Africa. Liverseed grass (*U. panicoides*) is cultivated on a small scale in Gujurat, India. The grain stores well and is often kept as a buffer against famine years.

Kodo millet *Paspalum scrobiculatum*

Kodo millet was domesticated in India by 2000 BC, and is still cultivated in central India. It is generally regarded as an indigestible, low quality food, but is a useful crop on poor soils. The grains are consumed whole, like rice, or are roasted and ground into flour.

Pearl millet *Pennisetum glaucum*

The wild ancestor of cultivated pearl millet, *P. violaceum,* is harvested as a wild cereal during times of scarcity. Archaeological evidence suggests that it was harvested as a wild cereal before the advent of agriculture in tropical west Africa some 3000 to 4000 years ago. Genetic evidence points to west Africa as the most likely region of domestication; the earliest archaeobotanical finds are in Mauritania and Nigeria, dating to about 1000 BC. Sporadic records of pearl millet occur at Indian archaeological sites from about 2000 BC.

Pearl millet is an important grain crop in Africa and India. It tolerates drought and heat and grows mainly under rainfed conditions, and thus has a vital role on land too dry for sorghum or corn. It is mostly consumed as a porridge or gruel in Africa and as flat unleavened bread in India. The stalks are used for thatching and building. In other parts of the world (the United States, Canada, and Australia) it is grown as a green fodder crop and as feed grain for animals. As with

finger millet, pearl millet is in danger of being displaced by crops, such as corn, that have been the subject of successful crop improvement programs.

See: Origins and Spread of Agriculture, p. 19

Rice *Oryza sativa*

Rice is the staple food of about half the world's population, mainly in Asia, and is now cultivated in most areas that have abundant water and hot summers. The history of rice domestication is still unclear. Its wild ancestor, *O. rufipogon*, grows throughout south and southeast Asia, and finds of rice at early sites in the region may derive from harvesting of wild grain. Dating of sites is often unclear. The earliest records of domesticated rice are probably those from the Yangtze river valley of southern China, dating to about 8000 to 6000 ^{14}C years ago. There are two main groups of rice varieties: the *japonica* group, which has short grains, and the *indica* group, which has long grains. Genetic evidence suggests that each group may have been independently domesticated. However suggestions that *indica* rice was domesticated in northeast India are not supported by archaeological evidence, which dates the first rice cultivation in the Indian subcontinent to about 2500 BC. It was cultivated in the Near East in the Hellenistic period (from 300 BC) and was traded throughout the Roman empire. However its cultivation in southern Europe did not begin until the medieval period. Rice was also a late arrival in Japan, coming from Korea at the beginning of the Yayoi culture in 400 BC. Archaeological and historical evidence suggests that rice spread slower than most crops, in part owing to its specialized need for abundant water. For example, rice did not become an important crop in North America until the late 17th century.

In dry or upland cultivation, rice is grown on hillsides as a rainfed crop similar to other cereals. Dry cultivation is mainly important in South America and Africa. In wet or lowland systems, most important in Asia, rice is grown on irrigated or flooded paddies. The seeds are often sown in a nursery and then transplanted into paddies. Deep-water rice is grown in water 30 inches (50 cm) or more deep, and is important in Bangladesh and other areas with deeply flooded river valleys. The rice plant has fast-growing stems that grow in pace with the rising water, up to a maximum of 14 feet (4 m). Much of the nutrition for deep-water rice is provided by the silt deposits borne by the flood water.

After harvest, rice must be dehusked to remove the inedible hull (lemma and palea). This is often carried out using a wooden mortar and pestle. The resulting grains are usually eaten as white, polished rice from which the bran has been removed. Whole "brown" rice is mainly popular as a "health food" in Western countries. Rice is most often consumed as whole grains boiled or steamed in water. Rice flour lacks gluten and so is usually consumed as noodles; this absence of gluten results in poor quality bread. Rice cultivars with starch that is low in amylose are waxy or glutinous, and are used industrially as a thickening agent for sauces and puddings, and in East Asia for snack foods such as rice crackers and cakes. In India rice is often parboiled prior to dehusking. This partially cooks the starch, which eases dehusking and milling.

Red rice (*O. glaberrima*) was an important locally domesticated cereal in west and central tropical Africa, but is increasingly being replaced by the Asian rice (*O. sativa*), which reached Africa in the 16th century. The wild ancestor of red rice, *O. barthii*, was probably domesticated in the valley of the Niger river 2000 to 3000 years ago.

Sawa millet *Echinochloa frumentacea*

This millet is widely grown as a cereal in India, Pakistan, and Nepal. Its wild ancestor is the tropical grass *E. colona*, but the exact date or region of domestication is uncertain. It is cultivated on marginal lands where rice and other crops will not grow well. The grains are cooked in water, like rice, or boiled with milk and sugar. Sometimes it is fermented to make beer. The closely related Japanese

barnyard millet (*Echinochloa esculenta*) is cultivated on a small scale in Japan, China, and Korea, both as a food and for animal fodder. It is grown in areas where the land is unsuitable or the climate too cool for paddy rice cultivation. However, the development of rice varieties that can withstand cold has led to a sharp decline in the cultivation of sawa millet, in favor of that rice. Sawa millet's wild ancestor is *Echinochloa crus-galli*, a widespread temperate grass; the earliest records of the domesticated form date to 2000 BC from the Jomon period of Japan.

Sorghum *Sorghum bicolor*

Sorghum is an ancient staple food plant in Africa and Asia, and a relatively recent introduction to the Americas, where it is used as animal feed and for industrial purposes. Sorghum's wild ancestor is *S. verticilliflorum*, a wild grass that grows throughout tropical Africa. The earliest archaeobotanical records of domesticated sorghum in Africa are from Sudan and Cameroon, dating to 100 to 500 AD. However, finds from India that show sorghum had reached south Asia by 2000 BC indicate that domestication must have occurred earlier in Africa. Botanical evidence points to Ethiopia or Chad as the most likely area of origin.

Domesticated sorghums are highly diverse in appearance and food properties, but can be grouped into five broad races or groups within the species *S. bicolor. Durra* is the most important race in India and is widely grown in arid sub-Saharan Africa, as is *Caudatum. Guinea* sorghum is grown in humid west Africa, *Kafir* sorghums in southern Africa, and the low-yielding, rather primitive, *Bicolor* sorghums on a small scale in Africa and Asia. Sorghum is the most important cereal in sub-Saharan Africa, where it has proved highly adaptable to extremes of temperature and drought. However, like corn (*Zea mays*), the grain needs processing to improve its nutritional value. About sixty percent of its protein is in the form of prolamine, of low nutritive value. Additionally, dark-seeded forms contain tannins that protect them from bird predation but taste bitter and interfere with digestion. To counter these, sorghum is often consumed in fermented form, as beer or sourdough bread, as fermentation breaks down tannins and prolamine to more digestible forms. Sorghum is also eaten as porridge, dumplings, breads, and whole grains.

Sorghum was introduced to the Americas in the 18th century, and is an important crop in the Great Plains of North America, in Mexico, and in Argentina. In these countries intensive breeding and production have led to high yields of grain, used primarily for animal feed. Forms of sorghum in the *Bicolor* group with sugar-filled stems (sometimes known as sorgho or *S. saccharatum*) were introduced to the southern United States in the mid-19th century. For a hundred years sorghum molasses was a popular sweetener in the region; it remains popular in China. Another *Bicolor* sorghum is broomcorn. As its name suggests, this has very long bristles on the flower head, which are used in the manufacture of brooms. It is first recorded in 16th-century Europe, and is still important in southern Europe and the United States.

Sorghum has not yet attracted the same amount of research as the other major cereals, wheat, rice, and corn. However, with rapidly increasing interest in its food and industrial properties, cultivation of this crop, ranking fourth amongst cereals in world production, is likely to expand. In addition to their importance as foods, sorghum stems and leaves are important sources of animal fodder and building materials.

See: Origins and Spread of Agriculture, p. 19; Caffeine, Alcohol, and Sweeteners, p. 181

Teff *Eragrostis tef*

Teff is native to and (until recently) only grown in Ethiopia, where it is the most important and ancient cereal, grown at altitudes from 4300 to 9200 feet (1300 to 2800 m). Some 2000 varieties are known. The grain is ground to a flour used for making a bread, *injera*, the staple food of Ethiopia.

The grains of teff are unusually small for a cultivated cereal, but are exceptionally rich in minerals and other nutrients. Increased interest in novel foods, particularly those that are gluten-free, has led to the cultivation of teff in North America.

Pseudocereals (non grasses)

Amaranth *Amaranthus* spp.

Amaranthaceae

Inca wheat, *Amaranthus caudatus*, was domesticated in the high Andes and is still cultivated by the Quechua Indians sparsely, but over a wide region. It is mainly intercropped with corn or quinoa. The seeds are usually roasted or popped, and are often consumed as balls mixed with molasses.

A. cruentus and *A. hypochondriacus* were domesticated in Mesoamerica. Amaranth, known as *huautli*, was as important as beans and corn to the Aztec civilization of Mexico. The early Spanish conquerors noted that it was used in tortillas made from popped grains, and in a range of drinks. Popped amaranth tamale breads were offered to the fire god Xiuhtecutli in Aztec rituals. A mixture of popped amaranth and the syrup of maguey cactus (*Agave cantula*) played a key role in a form of communion that honored the gods. Cultivation rapidly declined after the Spanish conquest, perhaps in part because of Christian disapproval of these practices. The domestication and early history of the New World amaranth species is not well documented, but it is likely that cultivation of all three species dates back at least 4000 years. All three species are increasingly cultivated in south Asia.

Many amaranths are gathered or cultivated elsewhere, but as leafy vegetables.

See: Gathering Food from the Wild, p. 33; Herbs and Vegetables, p. 113

Buckwheat *Fagopyrum esculentum*

Polygonaceae

Buckwheat is thought to have been domesticated in China about 1000 BC and reached Japan by 722 AD. Its heartland of cultivation is the mountainous area stretching from northern India through Nepal and China to Korea and Japan. Buckwheat was cultivated in the steppes north of the Black Sea by the Iron Age (500 BC), arriving during the medieval period in Europe, where it was eventually widely grown.

The plant is an erect annual herb, bearing its fruits in clusters. The fruits are three-sided, dark-brown nutlets. Buckwheat is particularly well adapted to cold climates and poor, light soils. Its cultivation in Europe began to decline with the introduction of fertilizers in the early 20th century, because other cereals respond better to increased soil fertility. However increasing interest in health foods has led to a revival of interest in buckwheat in the West. Cultivation remains important in Brittany because of the use of buckwheat flour in local savory pancakes known as *galettes*. The best-known buckwheat dish is *kasha*, an eastern European and Russian porridge made from cooked grains. In Japan buckwheat noodles are known as *soba*. Tartary buckwheat (*F. tataricum*) is an uncommon grain crop of Siberia.

Quinoa *Chenopodium quinoa*

Chenopodiaceae

Quinoa bears very small lens-shaped, black seeds in dense terminal clusters. It was taken into domestication in the high Andes of South America, probably from wild *C. hircinum* plants in southern Peru or Bolivia. Unlike another crop of the high Andes, the potato, quinoa has not spread far from its area of origin. Domesticated quinoa has been found at sites in the region dating to 4000 ^{14}C years ago, and is still an important staple food. It grows at altitudes—up to 13,000 feet (4000 m)—that are too high for corn. After removal of the toxic saponin-rich seed coat, the seeds

are traditionally washed in an alkaline solution to remove any remaining toxicity. Saponin content varies markedly between different landraces.

Quinoa seeds have a wide range of uses, including as whole grains and as flour for bread, tortillas, and soups. With a high protein content, averaging sixteen percent, and a good range of essential amino acids, quinoa is becoming popular as a health food and it is now widely available in specialist shops in Europe and North America. Increased trade may help to ensure continued cultivation of this ancient species. Canihua (*C. pallidicaule*) also originated in the high Andes and has similar uses. Huauzontle (*C. nuttalliae*) was domesticated in Mexico. The seeds are used, and the immature seed heads are also eaten, fried in batter. In eastern North America *C. berlandieri* was domesticated about 3500 ^{14}C years ago; however, despite being recorded by travelers in the 1720s, the domesticated plant was apparently extinct by the end of the 18th century.

Fat hen (*C. album*) is the Old World counterpart of quinoa. Domesticated forms are cultivated on a small scale in Nepal and northern India for bread, gruel, and fermented beverages.

See: Origins and Spread of Agriculture, p. 22; Herbs and Vegetables, p. 119; Plants as Medicines, p. 234

References and Further Reading

General

Coe, S. 1994. *America's First Cuisines.* Austin: University of Texas Press.
Foster, N., and Cordell, L.S. (Eds.). 1992. *Chilies to Chocolate: Food the Americas Gave the World.* Tucson: University of Arizona Press.
Grubben, G.J.H., and Partohardjono, S. (Eds.). 1996. *Plant Resources of South-east Asia. 10. Cereals.* Leiden: Backhuys.
National Research Council (Ed.). 1989. *Lost Crops of the Incas: Little-known Plants of the Andes with Promise for Worldwide Cultivation.* Washington, DC: National Academy Press.
National Research Council (Ed.). 1996. *Lost Crops of Africa. 1. Grains.* Washington, DC: National Academy Press.
Walker, H. (Ed.). 1990. *Staple Foods.* Proceedings of the Oxford symposium on food and cookery. London: Prospect Books.

Wild grains

Cane, S. 1989. Australian Aboriginal seed grinding and its archaeological record: A case study from the Western Desert. In *Foraging and Farming. The Evolution of Plant Exploitation*, edited by D.R. Harris and G.C. Hillman. London: Unwin Hyman, 99–119.
Cowan, C.W. 1978. The prehistoric use and distribution of Maygrass in eastern North America: cultural and phytogeographical implications. In *The Nature and Status of Ethnobotany,* edited by R.I. Ford. Ann Arbor: Museum of Anthropology, University of Michigan, 263–288.
Donkin, R.A. 1980. *Manna: An Historical Geography.* The Hague: W. Junk.
Guðmundsson, G. 1996. Gathering and processing of lyme-grass (*Elymus arenarius* L.) in Iceland: An ethnohistorical account. *Vegetation History and Archaeobotany 5,* 13–23.
Harlan, J.R. 1989. Wild-grass seed harvesting in the Sahara and sub-Sahara of Africa. In *Foraging and Farming. The Evolution of Plant Exploitation,* edited by D.R. Harris and G.C. Hillman. London: Unwin Hyman, 79–98.
Harris, D.R. 1984. Ethnohistorical evidence for the exploitation of wild grasses and forbs: Its scope and archaeological implications. In *Plants and Ancient Man. Studies in Palaeoethnobotany,* edited by W. van Zeist and W.A. Casparie. Rotterdam: A.A. Balkema, 63–69.
Nabhan, G., and de Wet, J.M.J. 1984. *Panicum sonorum* in Sonoran Desert agriculture. *Economic Botany 38,* 65–82.

Temperate cereals

Bonjean, A.P., and Angus, W.J. (Eds.). 2001. *The World Wheat Book: A History of Wheat Breeding.* Andover: Intercept.
Briggs, D.E. 1978. *Barley.* London: Chapman & Hall.
Caligari, P.D.S., and Brandham, P.E. (Eds.). 2001. *Wheat Taxonomy: The Legacy of John Percival.* Linnean Special Issue 3. London: Linnean Society.
Gupta, P.K., and Priyadarshan, P.M. 1982. Triticale: Present Status and Future Prospects. *Advances in Genetics 21,* 255–345.
Hillman, G.C. 1978. On the origins of domestic rye—*Secale cereale*: The finds from Aceramic Can Hasan III in Turkey. *Anatolian Studies 28,* 157–174.
Lockhart, G.W. 1997. *The Scots and Their oats.* Edinburgh: Birlinn.

Nesbitt, M., and Summers, G.D. 1988. Some recent discoveries of millet (*Panicum miliaceum* L. and *Setaria italica* (L.) P. Beauv.) at excavations in Turkey and Iran. *Anatolian Studies 38,* 85–97.
Padulosi, S., Hammer, K., and Heller, J. (Eds.). 1996. *Hulled Wheats. Proceedings of the First International Workshop on Hulled Wheats.* Rome: International Plant Genetic Resources Institute.
Pomeranz, Y. (Ed.). 1988. *Wheat: Chemistry and Technology.* [Two volumes.] St. Paul: American Association of Cereal Chemists.
Welch, R.W. 1995. *Oat Crop: Production and Utilization.* London: Chapman & Hall.

Tropical cereals

de Wet, J.M.J., et al. 1983. Domestication of sawa millet (*Echinochloa colona*). *Economic Botany 37,* 283–291.
Dirar, H.A. 1993. Indigenous Fermented Foods of the Sudan: A Study in African Food and Nutrition. Wallingford: CAB International.
Doggett, H. 1988. Sorghum. Harlow: Longman.
Fussell, B. 1992. The Story of Corn. New York: Alfred A. Knopf.
Grist, D.H. 1986. Rice (6th ed.). London: Longman.
Hilu, K.W., et al. 1997. Fonio millets: Ethnobotany, genetic diversity and evolution. South African Journal of Botany 63, 185–190.
Johannessen, S., and Hastorf, C. (Eds.). 1994. Corn and Culture in the Prehistoric New World. Westview, Boulder, CO.
Kimata, M., Ashok, E.G., and Seetharam, A. 2000. Domestication, cultivation and utilization of two small millets, Brachiaria ramosa and Setaria glauca (Poaceae), in South India. Economic Botany 54, 217–227.
Luh, B.S. (Ed.). 1991. Rice (2nd ed.). New York: AVI.
Owen, S. 1993. The Rice Book: The Definitive Book on the Magic of Rice Cookery. London: Doubleday.
Portères, R. 1955. Les céreales mineures du genre Digitaria en Afrique et en Europe. *Journal d'Agriculture Traditionnelle et de Botanique Appliquée 2,* 349–386, 477–510, 646–675.
Seetharam, A., Riley, K.W., and Harinarayana, G. (Eds.). 1990. *Small millets in global agriculture.* London: Aspect Publishing.
Williams, J.T. (Ed.). 1995. *Cereals and Pseudocereals.* London: Chapman & Hall.
Yukino, O. 2002. Domestication and cultivation of edible job's tears (*Coix lacryma-jobi* subsp. *ma-yuen*) under the influence of vegeculture. In *Vegeculture in Eastern Asia and Oceania,* edited by S. Yoshida and P.J. Matthews. Osaka: Japan Center for Area Studies, National Museum of Ethnology, 59–75.

Pseudocereals

Campbell, C.G. 1997. *Buckwheat.* Rome: International Plant Genetic Resources Institute.
National Research Council (Ed.). 1984. *Amaranth: Modern Prospects for an Ancient Crop.* Washington, DC: National Academy Press.