Cotton

Cotton is a soft, fluffy staple fiber that grows in a boll, or protective case, around the seeds of the cotton plants of the genus Gossypium in the mallow family Malvaceae. The fiber is almost pure cellulose, and can contain minor percentages of waxes, fats, pectins, and water. Under natural conditions, the cotton bolls will increase the dispersal of the seeds.

The plant is a shrub native to tropical and subtropical regions around the world, including the Americas, Africa, Egypt and India. The greatest diversity of wild cotton species is found in Mexico, followed by Australia and Africa.[1] Cotton was independently domesticated in the Old and New Worlds.[2]

The fiber is most often spun into yarn or thread and used to make a soft, breathable, and durable textile. The use of cotton for fabric is known to date to prehistoric times; fragments of cotton fabric dated to the fifth millennium BC have been found in the Indus Valley civilization, as well as fabric remnants dated back to 4200 BC in Peru. Although cultivated since antiquity, it was the invention of the cotton gin that lowered the cost of production that led to its widespread use, and it is the most widely used natural fiber cloth in clothing today.

Current estimates for world production are about 25 million tonnes or 110 million bales annually, accounting for 2.5% of the world's arable land. India is the world's largest producer of cotton. The United States has been the largest exporter for many years.[3]

Cotton ready for harvest in Andhra Pradesh, India.

Types

There are four commercially grown species of cotton, all domesticated in antiquity:

Gossypium hirsutum – upland cotton, native to Central America, Mexico, the Caribbean and southern Florida (90% of world production)[3]

Gossypium barbadense – known as extra-long staple cotton, native to tropical South America (over 5% of world production)[4]

Gossypium arboreum – tree cotton, native to India and Pakistan (less than 2%)

Gossypium herbaceum – Levant cotton, native to southern Africa and the Arabian Peninsula (less than 2%)

Hybrid varieties are also cultivated.[5] The two New World cotton species account for the vast majority of modern cotton production, but the two Old World species were widely used before the 1900s. While cotton fibers occur naturally in colors of white, brown, pink and green, fears of contaminating the genetics of white cotton have led many cotton-growing locations to ban the growing of colored cotton varieties.

Etymology

The word "cotton" has Arabic origins, derived from the Arabic word قطن (qutn or qutun). This was the usual word for cotton in medieval Arabic.[6] Marco Polo in chapter 2 in his book, describes a province he calls Khotan in Turkestan, today's Xinjiang, where cotton was grown in abundance. The word entered the Romance languages in the mid-12th century,[7] and English a century later. Cotton fabric was known to the ancient Romans as an import, but cotton was rare in the Romance-speaking lands until imports from the Arabic-speaking lands in the later medieval era at transformatively lowered prices.[8][9]

History

Main article: History of cotton

Early history

South Asia

Further information: Tree cotton

Mehrgarh shown in a physical map of the surrounding region

The earliest evidence of the use of cotton in the Old World, dated to 5500 BC and preserved in copper beads, has been found at the Neolithic site of Mehrgarh, at the foot of the Bolan Pass in ancient India, today in Balochistan Pakistan.[10][11][12] Fragments of cotton textiles have been found at Mohenjo-daro and other sites of the Bronze Age Indus Valley civilization, and cotton may have been an important export from it.[13]

Americas

Cotton bolls discovered in a cave near Tehuacán, Mexico, have been dated to as early as 5500 BC, but this date has been challenged.[14] More securely dated is the domestication of Gossypium hirsutum in Mexico between around 3400 and 2300 BC.[15] During this time, people between the Río Santiago and the Río Balsas grew, spun, wove, dyed, and sewed cotton. What they did not use themselves, they sent to their Aztec rulers as tribute, on the scale of ~116 million pounds annually.[16]

In Peru, cultivation of the indigenous cotton species Gossypium barbadense has been dated, from a find in Ancon, to c. 4200 BC,[17] and was the backbone of the development of coastal cultures such as the Norte Chico, Moche, and Nazca. Cotton was grown upriver, made into nets, and traded with fishing villages along the coast for large supplies of fish. The Spanish who came to Mexico and Peru in the early 16th century found the people growing cotton and wearing clothing made of it.

Arabia

The Greeks and the Arabs were not familiar with cotton until the Wars of Alexander the Great, as his contemporary Megasthenes told Seleucus I Nicator of "there being trees on which wool grows" in "Indica."[citation needed] This may be a reference to "tree cotton", Gossypium arboreum, which is native to the Indian subcontinent.

According to the Columbia Encyclopedia:[18]

Cotton has been spun, woven, and dyed since prehistoric times. It clothed the people of ancient India, Egypt, and China. Hundreds of years before the Christian era, cotton textiles were woven in India with matchless skill, and their use spread to the Mediterranean countries.

Iran

In Iran (Persia), the history of cotton dates back to the Achaemenid era (5th century BC); however, there are few sources about the planting of cotton in pre-Islamic Iran. Cotton cultivation was common in Merv, Ray and Pars. In Persian poems, especially Ferdowsi's Shahname, there are references to cotton ("panbe" in Persian). Marco Polo (13th century) refers to the major products of Persia, including cotton. John Chardin, a French traveler of the 17th century who visited Safavid Persia, spoke approvingly of the vast cotton farms of Persia.[19]

Kingdom of Kush

Cotton (Gossypium herbaceum Linnaeus) may have been domesticated 5000 BC in eastern Sudan near the Middle Nile Basin region, where cotton cloth was being produced.[20] Around the 4th century BC, the cultivation of cotton and the knowledge of its spinning and weaving in Meroë reached a high level. The export of textiles was one of the sources of wealth for Meroë. Ancient Nubia had a "culture of cotton" of sorts, evidenced by physical evidence of cotton processing tools and the presence of cattle in certain areas. Some researchers propose that cotton was important to the Nubian economy for its use in contact with the neighboring Egyptians.[21] Aksumite King Ezana boasted in his inscription that he destroyed large cotton plantations in Meroë during his conquest of the region.[22]

In the Meroitic Period (beginning 3rd century BCE), many cotton textiles have been recovered, preserved due to favorable arid conditions.[21] Most of these fabric fragments come from Lower Nubia, and the cotton textiles account for 85% of the archaeological textiles from Classic/Late Meroitic sites.[23] Due to these arid conditions, cotton, a plant that usually thrives moderate rainfall and richer soils, requires extra irrigation and labor in Sudanese climate conditions. Therefore, a great deal of resources would have been required, likely restricting its cultivation to the elite.[23] In the first to third centuries CE, recovered cotton fragments all began to mirror the same style and production method, as seen from the direction of spun cotton and technique of weaving.[23] Cotton textiles also appear in places of high regard, such as on funerary stelae and statues.[23]

China

During the Han dynasty (207 BC - 220 AD), cotton was grown by Chinese peoples in the southern Chinese province of Yunnan.[24]

Middle Ages

Eastern world

Egyptians grew and spun cotton in the first seven centuries of the Christian era.[25]

Handheld roller cotton gins had been used in India since the 6th century, and was then introduced to other countries from there.[26] Between the 12th and 14th centuries, dual-roller gins appeared in India and China. The Indian version of the dual-roller gin was prevalent throughout the Mediterranean cotton trade by the 16th century. This mechanical device was, in some areas, driven by water power.[27]

The earliest clear illustrations of the spinning wheel come from the Islamic world in the eleventh century.[28] The earliest unambiguous reference to a spinning wheel in India is dated to 1350, suggesting that the spinning wheel was likely introduced from Iran to India during the Delhi Sultanate.[29]

Europe

Cotton plants as imagined and drawn by John Mandeville in the 14th century
During the late medieval period, cotton became known as an imported fiber in northern Europe, without any knowledge of how it was derived, other than that it was a plant. Because Herodotus had written in his Histories, Book III, 106, that in India trees grew in the wild producing wool, it was assumed that the plant was a tree, rather than a shrub. This aspect is retained in the name for cotton in several Germanic languages, such as German Baumwolle, which translates as "tree wool" (Baum means "tree"; Wolle means "wool"). Noting its similarities to wool, people in the region could only imagine that cotton must be produced by plant-borne sheep. John Mandeville, writing in 1350, stated as fact that "There grew there [India] a wonderful tree which bore tiny lambs on the endes of its branches. These branches were so pliable that they bent down to allow the lambs to feed when they are hungry." (See Vegetable Lamb of Tartary.)

The Vegetable Lamb of Tartary
Cotton manufacture was introduced to Europe during the Muslim conquest of the Iberian Peninsula and Sicily. The knowledge of cotton weaving was spread to northern Italy in the 12th century, when Sicily was conquered by the Normans, and consequently to the rest of Europe. The spinning wheel, introduced to Europe circa 1350, improved the speed of cotton spinning.[30] By the 15th century, Venice, Antwerp, and Haarlem were important ports for cotton trade, and the sale and transportation of cotton fabrics had become very profitable.[31]

Early modern period
Mughal India
Main articles: Mughal Empire and Muslin trade in Bengal
Further information: Economic history of India

A woman in Dhaka clad in fine Bengali muslin, 18th century
Under the Mughal Empire, which ruled in the Indian subcontinent from the early 16th century to the early 18th century, Indian cotton production increased, in terms of both raw cotton and cotton textiles. The Mughals introduced agrarian reforms such as a new revenue system that

was biased in favour of higher value cash crops such as cotton and indigo, providing state incentives to grow cash crops, in addition to rising market demand.[32]

The largest manufacturing industry in the Mughal Empire was cotton textile manufacturing, which included the production of piece goods, calicos, and muslins, available unbleached and in a variety of colours. The cotton textile industry was responsible for a large part of the empire's international trade.[33] India had a 25% share of the global textile trade in the early 18th century.[34] Indian cotton textiles were the most important manufactured goods in world trade in the 18th century, consumed across the world from the Americas to Japan.[35] The most important center of cotton production was the Bengal Subah province, particularly around its capital city of Dhaka.[36]

The worm gear roller cotton gin, which was invented in India during the early Delhi Sultanate era of the 13th–14th centuries, came into use in the Mughal Empire some time around the 16th century,[37] and is still used in India through to the present day.[26] Another innovation, the incorporation of the crank handle in the cotton gin, first appeared in India some time during the late Delhi Sultanate or the early Mughal Empire.[38] The production of cotton, which may have largely been spun in the villages and then taken to towns in the form of yarn to be woven into cloth textiles, was advanced by the diffusion of the spinning wheel across India shortly before the Mughal era, lowering the costs of yarn and helping to increase demand for cotton. The diffusion of the spinning wheel, and the incorporation of the worm gear and crank handle into the roller cotton gin, led to greatly expanded Indian cotton textile production during the Mughal era.[39]

It was reported that, with an Indian cotton gin, which is half machine and half tool, one man and one woman could clean 28 pounds of cotton per day. With a modified Forbes version, one man and a boy could produce 250 pounds per day. If oxen were used to power 16 of these machines, and a few people's labour was used to feed them, they could produce as much work as 750 people did formerly.[40]

Egypt

Main article: History of Egypt under the Muhammad Ali dynasty

A group of Egyptian fellahs picking cotton by hand

In the early 19th century, a Frenchman named M. Jumel proposed to the great ruler of Egypt, Mohamed Ali Pasha, that he could earn a substantial income by growing an extra-long staple Maho (Gossypium barbadense) cotton, in Lower Egypt, for the French market. Mohamed Ali Pasha accepted the proposition and granted himself the monopoly on the sale and export of cotton in Egypt; and later dictated cotton should be grown in preference to other crops.

Egypt under Muhammad Ali in the early 19th century had the fifth most productive cotton industry in the world, in terms of the number of spindles per capita.[41] The industry was initially driven by machinery that relied on traditional energy sources, such as animal power, water wheels, and windmills, which were also the principal energy sources in Western Europe up until around 1870.[42] It was under Muhammad Ali in the early 19th century that steam engines were introduced to the Egyptian cotton industry.[42]

By the time of the American Civil war annual exports had reached $16 million (120,000 bales), which rose to $56 million by 1864, primarily due to the loss of the Confederate supply on the world market. Exports continued to grow even after the reintroduction of US cotton, produced now by a paid workforce, and Egyptian exports reached 1.2 million bales a year by 1903.

Britain

East India Company

Main articles: Calico Acts and Textile manufacture during the Industrial Revolution

Cotton bales at the port in Bombay, India, 1860s

The English East India Company (EIC) introduced the British to cheap calico and chintz cloth on the restoration of the monarchy in the 1660s. Initially imported as a novelty side line, from its spice trading posts in Asia, the cheap colourful cloth proved popular and overtook the EIC's spice trade by value in the late 17th century. The EIC embraced the demand, particularly for calico, by expanding its factories in Asia and producing and importing cloth in bulk, creating competition for domestic woollen and linen textile producers. The impacted weavers, spinners, dyers, shepherds and farmers objected and the calico question became one of the major issues of National politics between the 1680s and the 1730s. Parliament began to see a decline in domestic textile sales, and an increase in imported textiles from places like China and India. Seeing the East India Company and their textile importation as a threat to domestic textile businesses, Parliament passed the 1700 Calico Act, blocking the importation of cotton cloth. As there was no punishment for continuing to sell cotton cloth, smuggling of the popular material became commonplace. In 1721, dissatisfied with the results of the first act, Parliament passed a stricter addition, this time prohibiting the sale of most cottons, imported and domestic (exempting only thread Fustian and raw cotton). The exemption of raw cotton from the prohibition initially saw 2 thousand bales of cotton imported annually, to become the basis of a new indigenous industry, initially producing Fustian for the domestic market, though more importantly triggering the development of a series of mechanised spinning and weaving technologies, to process the material. This mechanised production was concentrated in new cotton mills, which slowly expanded until by the beginning of the 1770s seven thousand bales of cotton were imported annually, and pressure was put on Parliament, by the new mill owners, to remove the prohibition on the production and sale of pure cotton cloth, as they could easily compete with anything the EIC could import.

The acts were repealed in 1774, triggering a wave of investment in mill-based cotton spinning and production, doubling the demand for raw cotton within a couple of years, and doubling it again every decade, into the 1840s.[43]

Indian cotton textiles, particularly those from Bengal, continued to maintain a competitive advantage up until the 19th century. In order to compete with India, Britain invested in labour-saving technical progress, while implementing protectionist policies such as bans and tariffs to restrict Indian imports.[43] At the same time, the East India Company's rule in India contributed to its deindustrialization, opening up a new market for British goods,[43] while the capital amassed from Bengal after its 1757 conquest was used to invest in British industries such as textile manufacturing and greatly increase British wealth.[44][45] British colonization also forced open the large Indian market to British goods, which could be sold in India without tariffs or duties, compared to local Indian producers who were heavily taxed, while raw cotton was imported from India without tariffs to British factories which manufactured textiles from Indian cotton, giving Britain a monopoly over India's large market and cotton resources.[46][43][47] India served as both a significant supplier of raw goods to British manufacturers and a large captive market for British manufactured goods.[48] Britain eventually surpassed India as the world's leading cotton textile manufacturer in the 19th century.[43]

India's cotton-processing sector changed during EIC expansion in India in the late 18th and early 19th centuries. From focusing on supplying the British market to supplying East Asia with raw cotton.[49] As the Artisan produced textiles were no longer competitive with those produced Industrially, and Europe preferring the cheaper slave produced, long staple American, and Egyptian cottons, for its own materials.[citation needed]

Industrial Revolution
Main article: Textile manufacture during the Industrial Revolution

Slaves using the cotton gin to help harvest and process the cotton.
World map of cotton cultivation and export routes in 1907
World map of cotton cultivation and export routes in 1907
The advent of the Industrial Revolution in Britain provided a great boost to cotton manufacture, as textiles emerged as Britain's leading export. In 1738, Lewis Paul and John Wyatt, of Birmingham, England, patented the roller spinning machine, as well as the flyer-and-bobbin system for drawing cotton to a more even thickness using two sets of rollers that traveled at different speeds. Later, the invention of the James Hargreaves' spinning jenny in 1764, Richard Arkwright's spinning frame in 1769 and Samuel Crompton's spinning mule in 1775 enabled British spinners to produce cotton yarn at much higher rates. From the late 18th century on, the British city of Manchester acquired the nickname "Cottonopolis" due to the cotton industry's omnipresence within the city, and Manchester's role as the heart of the global cotton trade.

Production capacity in Britain and the United States was improved by the invention of the modern cotton gin by the American Eli Whitney in 1793. Before the development of cotton gins, the cotton fibers had to be pulled from the seeds tediously by hand. By the late 1700s, a number of crude ginning machines had been developed. However, to produce a bale of cotton required over 600 hours of human labor,[50] making large-scale production uneconomical in the United States, even with the use of humans as slave labor. The gin that Whitney manufactured (the Holmes design) reduced the hours down to just a dozen or so per bale. Although Whitney patented his own design for a cotton gin, he manufactured a prior design from Henry Odgen Holmes, for which Holmes filed a patent in 1796.[50] Improving technology and increasing control of world markets allowed British traders to develop a commercial chain in which raw cotton fibers were (at first) purchased from colonial plantations, processed into cotton cloth in the mills of Lancashire, and then exported on British ships to captive colonial markets in West Africa, India, and China (via Shanghai and Hong Kong).

By the 1840s, India was no longer capable of supplying the vast quantities of cotton fibers needed by mechanized British factories, while shipping bulky, low-price cotton from India to Britain was time-consuming and expensive. This, coupled with the emergence of American cotton as a superior type (due to the longer, stronger fibers of the two domesticated native American species, Gossypium hirsutum and Gossypium barbadense), encouraged British traders to purchase cotton from plantations in the United States and in the Caribbean. By the mid-19th century, "King Cotton" had become the backbone of the southern American economy. In the United States, cultivating and harvesting cotton became the leading occupation of slaves.

During the American Civil War, American cotton exports slumped due to a Union blockade on Southern ports, and because of a strategic decision by the Confederate government to cut exports, hoping to force Britain to recognize the Confederacy or enter the war. The Lancashire Cotton Famine prompted the main purchasers of cotton, Britain and France, to turn to Egyptian cotton. British and French traders invested heavily in cotton plantations. The Egyptian government of Viceroy Isma'il took out substantial loans from European bankers and stock exchanges. After the American Civil War ended in 1865, British and French traders abandoned Egyptian cotton and returned to cheap American exports,[citation needed] sending Egypt into a deficit spiral that led to the country declaring bankruptcy in 1876, a key factor behind Egypt's occupation by the British Empire in 1882.

Espanya Industrial" cotton factory, in Sants, Barcelona in the late 19th century.

During this time, cotton cultivation in the British Empire, especially Australia and India, greatly increased to replace the lost production of the American South. Through tariffs and other restrictions, the British government discouraged the production of cotton cloth in India; rather, the raw fiber was sent to England for processing. The Indian Mahatma Gandhi described the process:

English people buy Indian cotton in the field, picked by Indian labor at seven cents a day, through an optional monopoly.

This cotton is shipped on British ships, a three-week journey across the Indian Ocean, down the Red Sea, across the Mediterranean, through Gibraltar, across the Bay of Biscay and the Atlantic Ocean to London. One hundred per cent profit on this freight is regarded as small.

The cotton is turned into cloth in Lancashire. You pay shilling wages instead of Indian pennies to your workers. The English worker not only has the advantage of better wages, but the steel companies of England get the profit of building the factories and machines. Wages; profits; all these are spent in England.

The finished product is sent back to India at European shipping rates, once again on British ships. The captains, officers, sailors of these ships, whose wages must be paid, are English. The only Indians who profit are a few lascars who do the dirty work on the boats for a few cents a day.

The cloth is finally sold back to the kings and landlords of India who got the money to buy this expensive cloth out of the poor peasants of India who worked at seven cents a day.[51] United States

Main articles: Cotton production in the United States and Black Belt in the American South
Pictured is a black and white photograph, with a small African American boy in the center. He holds a basket of picked cotton. Behind him is his family bending over cotton plants. The picture is duplicated and the surrounding frame is that of a Keystone manufacturing company. A black family works a cotton plantation in Mississippi. The subtitle on the image reads "We's done all dis's mornin'".
In the United States, growing Southern cotton generated significant wealth and capital for the antebellum South, as well as raw material for Northern textile industries. Before 1865 the cotton was largely produced through the labor of enslaved African Americans. It enriched both the Southern landowners and the new textile industries of the Northeastern United States and northwestern Europe. In 1860 the slogan "Cotton is king" characterized the attitude of Southern leaders toward this monocrop in that Europe would support an independent Confederate States of America in 1861 in order to protect the supply of cotton it needed for its very large textile industry.[52]

Adams & Bazemore Cotton Warehouse, Macon, Georgia, c. 1877
Russell Griffin of California was a farmer who farmed one of the biggest cotton operations. He produced over sixty thousand bales.[53]

Cotton remained a key crop in the Southern economy after slavery ended in 1865. Across the South, sharecropping evolved, in which landless farmers worked land owned by others in return for a share of the profits. Some farmers rented the land and bore the production costs themselves. Until mechanical cotton pickers were developed, cotton farmers needed additional labor to hand-pick cotton. Picking cotton was a source of income for families across the South. Rural and small town school systems had split vacations so children could work in the fields during "cotton-picking."[54]

During the middle 20th century, employment in cotton farming fell, as machines began to replace laborers and the South's rural labor force dwindled during the World Wars. Cotton remains a major export of the United States, with large farms in California, Arizona and the Deep South.[55] To acknowledge cotton's place in the history and heritage of Texas, the Texas Legislature designated cotton the official "State Fiber and Fabric of Texas" in 1997.

The Moon
China's Chang'e 4 took cotton seeds to the Moon's far side. On 15 January 2019, China announced that a cotton seed sprouted, the first "truly otherworldly plant in history". Inside the Von Kármán Crater, the capsule and seeds sit inside the Chang'e 4 lander.[56]

Cultivation

Cotton field at Singalandapuram, Rasipuram, India (2017)
Cotton field

Cotton plant with Ipomoea quamoclit vine

A cotton field, late in the season

Cotton plowing in Togo, 1928

Picking cotton in Armenia in the 1930s. No cotton is grown there today.

Cotton ready for shipment, Houston, Texas (postcard, circa 1911)

Cotton modules in Australia (2007)

Round cotton modules in Australia (2014)

Successful cultivation of cotton requires a long frost-free period, plenty of sunshine, and a moderate rainfall, usually from 50 to 100 cm (19 to 39 in).[57] Soils usually need to be fairly heavy, although the level of nutrients does not need to be exceptional. In general, these conditions are met within the seasonally dry tropics and subtropics in the Northern and Southern hemispheres, but a large proportion of the cotton grown today is cultivated in areas with less rainfall that obtain the water from irrigation. Production of the crop for a given year usually starts soon after harvesting the preceding autumn. Cotton is naturally a perennial but is grown as an annual to help control pests.[58] Planting time in spring in the Northern hemisphere varies from the beginning of February to the beginning of June. The area of the United States known as the South Plains is the largest contiguous cotton-growing region in the world. While dryland (non-irrigated) cotton is successfully grown in this region, consistent yields are only produced with heavy reliance on irrigation water drawn from the Ogallala Aquifer. Since cotton is somewhat salt and drought tolerant, this makes it an attractive crop for arid and semiarid regions. As water resources get tighter around the world, economies that rely on it face difficulties and conflict, as well as potential environmental problems.[59][60][61][62][63] For example, improper cropping and irrigation practices have led to desertification in areas of Uzbekistan, where cotton is a major export. In the days of the Soviet Union, the Aral Sea was tapped for agricultural irrigation, largely of cotton, and now salination is widespread.[62][63]

Cotton can also be cultivated to have colors other than the yellowish off-white typical of modern commercial cotton fibers. Naturally colored cotton can come in red, green, and several shades of brown.[64]

Water footprint

The water footprint of cotton fibers is substantially larger than for most other plant fibers. Cotton is also known as a thirsty crop; on average, globally, cotton requires 8,000–10,000 liters of

water for one kilogram of cotton, and in dry areas, it may require even more such as in some areas of
India, it may need 22,500 liters.[65][66]

Genetic modification

Main article: Bt cotton

Genetically modified (GM) cotton was developed to reduce the heavy reliance on pesticides. The bacterium Bacillus thuringiensis (Bt) naturally produces a chemical harmful only to a small fraction of insects, most notably the larvae of moths and butterflies, beetles, and flies, and harmless to other forms of life.[67][68][69] The gene coding for Bt toxin has been inserted into cotton, causing cotton, called Bt cotton, to produce this natural insecticide in its tissues. In many regions, the main pests in commercial cotton are lepidopteran larvae, which are killed by the Bt protein in the transgenic cotton they eat. This eliminates the need to use large amounts of broad-spectrum insecticides to kill lepidopteran pests (some of which have developed pyrethroid resistance). This spares natural insect predators in the farm ecology and further contributes to noninsecticide pest management.

However, Bt cotton is ineffective against many cotton pests, such as plant bugs, stink bugs, and aphids; depending on circumstances it may still be desirable to use insecticides against these. A 2006 study done by Cornell researchers, the Center for Chinese Agricultural Policy and the Chinese Academy of Science on Bt cotton farming in China found that after seven years these secondary pests that were normally controlled by pesticide had increased, necessitating the use of pesticides at similar levels to non-Bt cotton and causing less profit for farmers because of the extra expense of GM seeds.[70] However, a 2009 study by the Chinese Academy of Sciences, Stanford University and Rutgers University refuted this.[71] They concluded that the GM cotton effectively controlled bollworm. The secondary pests were mostly miridae (plant bugs) whose increase was related to local temperature and rainfall and only continued to increase in half the villages studied. Moreover, the increase in insecticide use for the control of these secondary insects was far smaller than the reduction in total insecticide use due to Bt cotton adoption. A 2012 Chinese study concluded that Bt cotton halved the use of pesticides and doubled the level of ladybirds, lacewings and spiders.[72][73] The International Service for the Acquisition of Agri-biotech Applications (ISAAA) said that, worldwide, GM cotton was planted on an area of 25 million hectares in 2011.[74] This was 69% of the worldwide total area planted in cotton.

GM cotton acreage in India grew at a rapid rate, increasing from 50,000 hectares in 2002 to 10.6 million hectares in 2011. The total cotton area in India was 12.1 million hectares in 2011, so GM cotton was grown on 88% of the cotton area. This made India the country with the largest area of GM cotton in the world.[74] A long-term study on the economic impacts of Bt cotton in India, published in the Journal PNAS in 2012, showed that Bt cotton has increased yields, profits, and living standards of smallholder farmers.[75] The U.S. GM cotton crop was 4.0 million hectares in 2011 the second largest area in the world, the Chinese GM cotton crop was third largest by area with 3.9 million hectares and Pakistan had the fourth largest GM cotton crop area of 2.6 million hectares in 2011.[74] The initial introduction of GM cotton proved to be a success in Australia – the yields were equivalent to the non-transgenic varieties and the crop used much less pesticide to produce (85% reduction).[76] The subsequent introduction of a second variety of GM cotton led to increases in GM cotton production until 95% of the Australian cotton crop was GM in 2009[77] making Australia the country with the fifth largest GM cotton crop in the world.[74] Other GM cotton growing countries in 2011 were Argentina, Myanmar, Burkina Faso, Brazil, Mexico, Colombia, South Africa and Costa Rica.[74]

Cotton has been genetically modified for resistance to glyphosate a broad-spectrum herbicide discovered by Monsanto which also sells some of the Bt cotton seeds to farmers. There are also a number of other cotton seed companies selling GM cotton around the world. About 62% of the GM cotton grown from 1996 to 2011 was insect resistant, 24% stacked product and 14% herbicide resistant.[74]

Cotton has gossypol, a toxin that makes it inedible. However, scientists have silenced the gene that produces the toxin, making it a potential food crop.[78] On 17 October 2018, the USDA deregulated GE low-gossypol cotton.[79][80]

Organic production

Organic cotton is generally understood as cotton from plants not genetically modified and that is certified to be grown without the use of any synthetic agricultural chemicals, such as fertilizers or pesticides.[81] Its production also promotes and enhances biodiversity and biological cycles.[82]

In the United States, organic cotton plantations are required to enforce the National Organic Program (NOP). This institution determines the allowed practices for pest control, growing, fertilizing, and handling of organic crops.[83] As of 2007, 265,517 bales of organic cotton were produced in 24 countries, and worldwide production was growing at a rate of more than 50% per year.[84] Organic cotton products are now available for purchase at limited locations. These are popular for baby clothes and diapers; natural cotton products are known to be both sustainable and hypoallergenic.[citation needed]

Pests and weeds

Hoeing a cotton field to remove weeds, Greene County, Georgia, US, 1941

Female and nymph cotton harlequin bug

The cotton industry relies heavily on chemicals, such as fertilizers, insecticides and herbicides, although a very small number of farmers are moving toward an organic model of production. Under most definitions, organic products do not use transgenic Bt cotton which contains a bacterial gene that codes for a plant-produced protein that is toxic to a number of pests especially the bollworms. For most producers, Bt cotton has allowed a substantial reduction in the use of synthetic insecticides, although in the long term resistance may become problematic.

Global pest problems

Main article: List of cotton diseases

Significant global pests of cotton include various species of bollworm, such as Pectinophora gossypiella. Sucking pests include cotton stainers, the chili thrips, Scirtothrips dorsalis; the cotton seed bug, Oxycarenus hyalinipennis. Defoliators include the fall armyworm, Spodoptera frugiperda.
Cotton yield is threatened by the evolution of new biotypes of insects and of new pathogens.[85] Maintaining good yield requires strategies to slow these adversaries' evolution.[85]

A boll weevil on a cotton boll

North American insect pests

Historically, in North America, one of the most economically destructive pests in cotton production has been the boll weevil. Boll weevils are beetles who ate cotton in the 1950s, that slowed the production of the cotton industry drastically. "This bone pile of short budgets, loss of market share, failing prices, abandoned farms, and the new immunity of boll weevils generated a feeling of helplessness"[86] Boll Weevils first appeared in Beeville, Texas wiping out field after field of cotton in south Texas. This swarm of Boll Weevils swept through east Texas and spread to the eastern seaboard, leaving ruin and devastation in its path, causing many cotton farmers to go out of business.[87]

Due to the US Department of Agriculture's highly successful Boll Weevil Eradication Program (BWEP), this pest has been eliminated from cotton in most of the United States. This program, along with the introduction of genetically engineered Bt cotton, has improved the management of a number of pests such as cotton bollworm and pink bollworm). Sucking pests include the cotton stainer, Dysdercus suturellus and the tarnish plant bug, Lygus lineolaris. A significant cotton disease is caused by Xanthomonas citri subsp. malvacearum.

Harvesting

Offloading freshly harvested cotton into a module builder in Texas; previously built modules can be seen in the background

Cotton being picked by hand in India, 2005

Most cotton in the United States, Europe and Australia is harvested mechanically, either by a cotton picker, a machine that removes the cotton from the boll without damaging the cotton plant, or by a cotton stripper, which strips the entire boll off the plant. Cotton strippers are used in regions where it is too windy to grow picker varieties of cotton, and usually after application of a chemical defoliant or the natural defoliation that occurs after a freeze. Cotton is a perennial crop in the tropics, and without defoliation or freezing, the plant will continue to grow.

Cotton continues to be picked by hand in developing countries[88] and in Xinjiang, China, allegedly by forced labor.[89] Xinjiang produces over 20% of the world's cotton.[90]

Competition from synthetic fibers

The era of manufactured fibers began with the development of rayon in France in the 1890s. Rayon is derived from a natural cellulose and cannot be considered synthetic, but requires extensive processing in a manufacturing process, and led the less expensive replacement of more naturally derived materials. A succession of new synthetic fibers were introduced by the chemicals industry in the following decades. Acetate in fiber form was developed in 1924. Nylon, the first fiber synthesized entirely from petrochemicals, was introduced as a sewing thread by DuPont in 1936, followed by DuPont's acrylic in 1944. Some garments were created from fabrics based on these fibers, such as women's hosiery from nylon, but it was not until the introduction of polyester into the fiber marketplace in the early 1950s that the market for cotton came under threat.[91] The rapid uptake of polyester garments in the 1960s caused economic hardship in cotton-exporting economies, especially in Central American countries, such as Nicaragua, where cotton production had boomed tenfold between 1950 and 1965 with the advent of cheap chemical pesticides. Cotton production recovered in the 1970s, but crashed to pre-1960 levels in the early 1990s.[92]

Competition from natural fibers

High water and pesticide use in cotton cultivation has prompted sustainability concerns and created a market for natural fiber alternatives. Other cellulose fibers, such as hemp, are seen as more sustainable options because of higher yields per acre with less water and pesticide use than cotton.[93] Cellulose fiber alternatives have similar characteristics but are not perfect substitutes for cotton textiles with differences in properties like tensile strength and thermal regulation.

Uses

Workers sort through cotton to remove contaminants. The workers wear masks to reduce the number of fibers they inhale.

Cotton is used to make a number of textile products. These include terrycloth for highly absorbent bath towels and robes; denim for blue jeans; cambric, popularly used in the manufacture of blue work shirts (from which we get the term "blue-collar"); and corduroy, seersucker, and cotton twill. Socks, underwear, and most T-shirts are made from cotton. Bed sheets often are made from cotton. It is a preferred material for sheets as it is hypoallergenic, easy to maintain and non-irritant to the skin.[94] Cotton also is used to make yarn used in crochet and knitting. Fabric also can be made from recycled or recovered cotton that otherwise would be thrown away during the spinning, weaving, or cutting process. While many fabrics are made completely of cotton, some materials blend cotton with other fibers, including rayon and synthetic fibers such as polyester. It can either be used in knitted or woven fabrics, as it can be blended with elastine to make a stretchier thread for knitted fabrics, and apparel such as stretch jeans. Cotton can be blended also with linen producing fabrics with the benefits of both materials. Linen-cotton blends are wrinkle resistant and retain heat more effectively than only linen, and are thinner, stronger and lighter than only cotton.[95]

In addition to the textile industry, cotton is used in fishing nets, coffee filters, tents, explosives manufacture (see nitrocellulose), cotton paper, and in bookbinding. Fire hoses were once made of cotton.

The cottonseed which remains after the cotton is ginned is used to produce cottonseed oil, which, after refining, can be consumed by humans like any other vegetable oil. The cottonseed meal that is left generally is fed to ruminant livestock; the gossypol remaining in the meal is toxic to monogastric animals. Cottonseed hulls can be added to dairy cattle rations for roughage. During the American slavery period, cotton root bark was used in folk remedies as an abortifacient, that is, to induce a miscarriage. Gossypol was one of the many substances found in all parts of the cotton plant and it was described by the scientists as 'poisonous pigment'. It also appears to inhibit the development of sperm or even restrict the mobility of the sperm. Also, it is thought to interfere with the menstrual cycle by restricting the release of certain hormones.[96]

Cotton linters are fine, silky fibers which adhere to the seeds of the cotton plant after ginning. These curly fibers typically are less than 1⁄8 inch (3.2 mm) long. The term also may apply to the longer textile fiber staple lint as well as the shorter fuzzy fibers from some upland species. Linters are traditionally used in the manufacture of paper and as a raw material in the manufacture of cellulose. In the UK, linters are referred to as "cotton wool".

Cotton is made into balls, swabs, and pads for applying and removing cosmetics.
A less technical use of the term "cotton wool", in the UK and Ireland, is for the refined product known as "absorbent cotton" (or, often, just "cotton") in U.S. usage: fluffy cotton in sheets or balls used for medical, cosmetic, protective packaging, and many other practical purposes. The first medical use of cotton wool was by Sampson Gamgee at the Queen's Hospital (later the General Hospital) in Birmingham, England.

Long staple (LS cotton) is cotton of a longer fibre length and therefore of higher quality, while Extra-long staple cotton (ELS cotton) has longer fibre length still and of even higher quality. The name "Egyptian cotton" is broadly associated high quality cottons and is often an LS or (less often) an ELS cotton.[97] Nowadays the name "Egyptian cotton" refers more to the way cotton is treated and threads produced rather than the location where it is grown. The American cotton variety Pima cotton is often compared to Egyptian cotton, as both are used in high quality bed sheets and other cotton products. While Pima cotton is often grown in the American southwest,[98] the Pima name is now used by cotton-producing nations such as Peru, Australia and Israel.[99] Not all products bearing the Pima name are made with the finest cotton: American-grown ELS Pima cotton is trademarked as Supima cotton.[100] "Kasturi" cotton is a brand-building initiative for Indian long staple cotton by the Indian government. The PIB issued a press release announcing the same.[101][102][103][104][105]

Cottons have been grown as ornamentals or novelties due to their showy flowers and snowball-like fruit. For example, Jumel's cotton, once an important source of fiber in Egypt, started as an ornamental.[106] However, agricultural authorities such as the Boll Weevil Eradication Program in the United States discourage using cotton as an ornamental, due to concerns about these plants harboring pests injurious to crops.[107]

Cotton in a tree

International trade

Worldwide cotton production

The largest producers of cotton, as of 2017, are India and China, with annual production of about 18.53 million tonnes and 17.14 million tonnes, respectively; most of this production is consumed by their respective textile industries. The largest exporters of raw cotton are the United States, with sales of $4.9 billion, and Africa, with sales of $2.1 billion. The total international trade is estimated to be $12 billion. Africa's share of the cotton trade has doubled since 1980. Neither area has a significant domestic textile industry, textile manufacturing having moved to developing nations in Eastern and South Asia such as India and China. In Africa, cotton is grown by numerous small holders. Dunavant Enterprises, based in Memphis, Tennessee, is the leading cotton broker in Africa, with hundreds of purchasing agents. It operates cotton gins in Uganda, Mozambique, and Zambia. In Zambia, it often offers loans for seed and expenses to the 180,000 small farmers who grow cotton for it, as well as advice on farming methods. Cargill also purchases cotton in Africa for export.

The 25,000 cotton growers in the United States are heavily subsidized at the rate of $2 billion per year although China now provides the highest overall level of cotton sector support.[108] The future of these subsidies is uncertain and has led to anticipatory expansion of cotton brokers' operations in Africa. Dunavant expanded in Africa by buying out local operations. This is only possible in former British colonies and Mozambique; former French colonies continue to maintain tight monopolies, inherited from their former colonialist masters, on cotton purchases at low fixed prices.[109]

To encourage trade and organize discussion about cotton, World Cotton Day is celebrated every October 7.[110][111][112][105]

Leading producer countries

Top 10 cotton-producing countries (in tonnes)

Rank	Country	2021
1	China	17,910,606
2	India	17,731,050
3	United States	9,227,456
4	Brazil	7,070,136
5	Pakistan	3,454,334
6	Uzbekistan	3,063,998
7	Turkey	1,773,646
8	Turkmenistan	1,280,220
9	Argentina	1,046,043

10 Benin 731,057
Source: UN Food & Agriculture Organization[113]

The five leading exporters of cotton in 2019 are (1) India, (2) the United States, (3) China, (4) Brazil, and (5) Pakistan.
In India, the states of Maharashtra (26.63%), Gujarat (17.96%) and Andhra Pradesh (13.75%) and also Madhya Pradesh are the leading cotton producing states,[114] these states have a predominantly tropical wet and dry climate.

In the United States, the state of Texas led in total production as of 2004,[115] while the state of California had the highest yield per acre.[116]

Fair trade
Cotton is an enormously important commodity throughout the world. It provides livelihoods for up to 1 billion people, including 100 million smallholder farmers who cultivate cotton.[117] However, many farmers in developing countries receive a low price for their produce, or find it difficult to compete with developed countries.

This has led to an international dispute (see Brazil–United States cotton dispute):

On 27 September 2002, Brazil requested consultations with the US regarding prohibited and actionable subsidies provided to US producers, users and/or exporters of upland cotton, as well as legislation, regulations, statutory instruments and amendments thereto providing such subsidies (including export credits), grants, and any other assistance to the US producers, users and exporters of upland cotton.[118]

On 8 September 2004, the Panel Report recommended that the United States "withdraw" export credit guarantees and payments to domestic users and exporters, and "take appropriate steps to remove the adverse effects or withdraw" the mandatory price-contingent subsidy measures.[119]

While Brazil was fighting the US through the WTO's Dispute Settlement Mechanism against a heavily subsidized cotton industry, a group of four least-developed African countries – Benin, Burkina Faso, Chad, and Mali – also known as "Cotton-4" have been the leading protagonist for the reduction of US cotton subsidies through negotiations. The four introduced a "Sectoral Initiative in Favour of Cotton", presented by Burkina Faso's President Blaise Compaoré during the Trade Negotiations Committee on 10 June 2003.[120]

In addition to concerns over subsidies, the cotton industries of some countries are criticized for employing child labor and damaging workers' health by exposure to pesticides used in production. The Environmental Justice Foundation has campaigned against the prevalent use of forced child and adult labor in cotton production in Uzbekistan, the world's third largest cotton exporter.[121]

The international production and trade situation has led to "fair trade" cotton clothing and footwear, joining a rapidly growing market for organic clothing, fair fashion or "ethical fashion". The fair trade system was initiated in 2005 with producers from Cameroon, Mali and Senegal, with the Association Max Havelaar France playing a lead role in the establishment of this segment of the fair trade system in conjunction with Fairtrade International and the French organisation Dagris (Développement des Agro-Industries du Sud).[122]

Trade

Cotton prices 2009–2022
See also: 2020s commodities boom

A display from a British cotton manufacturer of items used in a cotton mill during the Industrial Revolution

A bale of cotton on display at the Louisiana State Cotton Museum in Lake Providence in East Carroll Parish in northeastern Louisiana
Cotton is bought and sold by investors and price speculators as a tradable commodity on 2 different commodity exchanges in the United States of America.

Cotton No. 2 futures contracts are traded on the ICE Futures US Softs (NYI) under the ticker symbol CT. They are delivered every year in March, May, July, October, and December.[123]
Cotton futures contracts are traded on the New York Mercantile Exchange (NYMEX) under the ticker symbol TT. They are delivered every year in March, May, July, October, and December.[124]
Contract specifications[123]
Cotton (CTA)
Exchange: NYI
Sector:Energy
Tick size: 0.01
Tick value: 5 USD
BPV: 500
Denomination:USD
Decimal place: 2
Critical temperatures
Favorable travel temperature range: below 25 °C (77 °F)
Optimum travel temperature: 21 °C (70 °F)
Glow temperature: 205 °C (401 °F)
Fire point: 210 °C (410 °F)
Autoignition temperature: 360 °C (680 °F) - 425 °C (797 °F)[125]
Autoignition temperature (for oily cotton): 120 °C (248 °F)

A temperature range of 25 to 35 °C (77 to 95 °F) is the optimal range for mold development. At temperatures below 0 °C (32 °F), rotting of wet cotton stops. Damaged cotton is sometimes stored at these temperatures to prevent further deterioration.[126]

Egypt has a unique climatic temperature that the soil and the temperature provide an exceptional environment for cotton to grow rapidly.

British standard yarn measures

1 thread = 55 in or 140 cm

1 skein or rap = 80 threads (120 yd or 110 m)

1 hank = 7 skeins (840 yd or 770 m)

1 spindle = 18 hanks (15,120 yd or 13.83 km)

Fiber properties

This section needs additional citations for verification. Please help improve this article by adding citations to reliable sources in this section. Unsourced material may be challenged and removed. (December 2012) (Learn how and when to remove this template message)

Property Evaluation

Shape Fairly uniform in width, 12–20 micrometers;
length varies from 1 cm to 6 cm (1⁄2 to 21⁄2 inches);
typical length is 2.2 cm to 3.3 cm (7⁄8 to 11⁄4 inches).

Luster High

Tenacity (strength)

Dry

Wet

3.0–5.0 g/d

3.3–6.0 g/d

Resiliency Low

Density 1.54–1.56 g/cm3

Moisture absorption
raw: conditioned
saturation mercerized:
conditioned saturation

8.5%
15–25%
8.5–10.3%
15–27%+

Dimensional stability Good

Resistance to acids alkali

organic solvents
sunlight
microorganisms
insects

Damage, weaken fibers
resistant; no harmful effects
high resistance to most
Prolonged exposure weakens fibers.
Mildew and rot-producing bacteria damage fibers.
Silverfish damage fibers.
Thermal reactions to
heat to flame
Decomposes after prolonged exposure to temperatures of 150 °C or over.
Burns readily with yellow flame, smells like burning paper. The residual ash is light and fluffy and greyish in color.[127]

Cotton fibers viewed under a scanning electron microscope
Depending upon the origin, the chemical composition of cotton is as follows:[128]

Cellulose 91.00%
Water 7.85%
Protoplasm, pectins 0.55%
Waxes, fatty substances 0.40%
Mineral salts 0.20%
Morphology
Cotton has a more complex structure among the other crops. A matured cotton fiber is a single, elongated complete dried multilayer cell that develops in the surface layer of cottonseed. It has the following parts.[129]

The cuticle is the outer most layer. It is a waxy layer that contains pectins and proteinaceous materials.[130]
The primary wall is the original thin cell wall. Primary wall is mainly cellulose, it is made up of a network of fine fibrils (small strands of cellulose).[130]
The winding layer is the first layer of secondary thickening it is also called the S1 layer . It is different in structure from both the primary wall and the remainder of the secondary wall. It consists of fibrils aligned at 40 to 70-degree angles to the fiber axis in an open netting type of pattern.[130]
The secondary wall consists of concentric layers of cellulose it is also called the S2 layer, that constitute the main portion of the cotton fiber. After the fiber has attained its maximum diameter, new layers of cellulose are added to form the secondary wall. The fibrils are deposited at 70 to 80-degree angles to the fiber axis, reversing angle at points along the length of the fiber.[130]
The lumen is the hollow canal that runs the length of the fiber. It is filled with living protoplasm during the growth period. After the fiber matures and the boll opens, the protoplast dries up, and the lumen naturally collapses, leaving a central void, or pore space, in each fiber. It separates the secondary wall from the lumen and appears to be more resistant to certain reagents than the secondary wall layers. The lumen wall also called the S3 layer.[130][131][129]
Dead cotton

Dead cotton is a term that refers to unripe cotton fibers that do not absorb dye.[132] Dead cotton is immature cotton that has poor dye affinity and appears as white specks on a dyed fabric. When cotton fibers are analyzed and assessed through a microscope, dead fibers appear differently. Dead cotton fibers have thin cell walls. In contrast, mature fibers have more cellulose and a greater degree of cell wall thickening[133]

Genome

This section needs to be updated. Relevant discussion may be found on the talk page. Please help update this article to reflect recent events or newly available information. (April 2021)

This article may be too technical for most readers to understand. Please help improve it to make it understandable to non-experts, without removing the technical details. (January 2011) (Learn how and when to remove this template message)

There is a public effort to sequence the genome of cotton. It was started in 2007 by a consortium of public researchers.[134] Their aim is to sequence the genome of cultivated, tetraploid cotton. "Tetraploid" means that its nucleus has two separate genomes, called A and D. The consortium agreed to first sequence the D-genome wild relative of cultivated cotton (G. raimondii, a Central American species) because it is small and has few repetitive elements. It has nearly one-third of the bases of tetraploid cotton, and each chromosome occurs only once.[clarification needed] Then, the A genome of G. arboreum would be sequenced. Its genome is roughly twice that of G. raimondii. Part of the difference in size is due to the amplification of retrotransposons (GORGE). After both diploid genomes are assembled, they would be used as models for sequencing the genomes of tetraploid cultivated species. Without knowing the diploid genomes, the euchromatic DNA sequences of AD genomes would co-assemble, and their repetitive elements would assemble independently into A and D sequences respectively. There would be no way to untangle the mess of AD sequences without comparing them to their diploid counterparts.

The public sector effort continues with the goal to create a high-quality, draft genome sequence from reads generated by all sources. The effort has generated Sanger reads of BACs, fosmids, and plasmids, as well as 454 reads. These later types of reads will be instrumental in assembling an initial draft of the D genome. In 2010, the companies Monsanto and Illumina completed enough Illumina sequencing to cover the D genome of G. raimondii about 50x.[135] They announced that they would donate their raw reads to the public. This public relations effort gave them some recognition for sequencing the cotton genome. Once the D genome is assembled from all of this raw material, it will undoubtedly assist in the assembly of the AD genomes of cultivated varieties of cotton, but much work remains.

As of 2014, at least one assembled cotton genome had been reported.

Rice

Rice is a cereal grain, and in its domesticated form is the staple food for over half of the world's human population, particularly in Asia and Africa, due to the vast amount of soil that is able to grow rice. Rice is the seed of the grass species *Oryza sativa* (Asian rice) or, much less commonly, *O. glaberrima* (African rice). Asian rice was domesticated in China some 13,500 to 8,200 years ago, while African rice was domesticated in Africa some 3,000 years ago. Rice has become commonplace in many cultures worldwide; in 2021, 787 million tons were produced, placing it fourth after sugarcane, maize, and wheat. Only some 8% of rice is traded internationally. China, India, and Indonesia are the largest consumers of rice. A substantial amount of the rice produced in developing nations is lost after harvest through factors such as poor transport and storage. Rice yields can be reduced by pests including insects, rodents, and birds, as well as by weeds, and by diseases such as rice blast. Traditional polycultures such as rice-duck farming, and modern integrated pest management seek to control damage from pests in a sustainable way.

Many varieties of rice have been bred to improve crop quality and productivity. Biotechnology has created Green Revolution rice able to produce high yields when supplied with nitrogen fertilizer and managed intensively. Other products are rice able to express human proteins for medicinal use; flood-tolerant or deepwater rice; and drought-tolerant and salt-tolerant varieties. Rice is used as a model organism in biology.

Dry rice grain is milled to remove the outer layers; depending on how much is removed, products range from brown rice to rice with germ and white rice. Some is parboiled to make it easy to cook. Rice contains no gluten; it provides protein but not all the essential amino acids needed for good health. Rice of different types is eaten around the world. Long-grain rice tends to stay intact on cooking; medium-grain rice is stickier, and is used for sweet dishes, and in Italy for risotto; and sticky short-grain rice is used in Japanese sushi as it keeps its shape when cooked. White rice when cooked contains 29% carbohydrate and 2% protein, with some manganese. Golden rice is a variety produced by genetic engineering to contain vitamin A.

Production of rice is estimated to have caused over 1% of global greenhouse gas emissions in 2022. Rice yields are predicted to fall by some 20% with each 1°C rise in global mean temperature. In human culture, rice plays a role in certain religions and traditions, such as in weddings.

Description

The rice plant can grow to over 1 m (3 ft) tall; if in deep water, it can reach a length of 5 m (16 ft). A single plant may have several leafy stems or tillers. The upright stem is jointed with nodes along its length; a long slender leaf arises from each node.[1] The self-fertile flowers are produced in a panicle, a branched inflorescence which arises from the last internode on the stem. There can be up to 350 spikelets in a panicle, each containing male and female flower parts (anthers and ovule). A fertilised ovule develops into the edible grain or caryopsis.[2]

Rice is a cereal belonging to the family Poaceae. As a tropical crop, it can be grown during the two distinct seasons (dry and wet) of the year provided that sufficient water is made available.[3] It is normally an annual, but in the tropics it can survive as a perennial, producing a ratoon crop.[4]

Agronomy

Growing

Like all crops, rice depends for its growth on both biotic and abiotic environmental factors. The principal biotic factors are crop variety, pests, and plant diseases. Abiotic factors include the soil type, whether lowland or upland, amount of rain or irrigation water, temperature, day length, and intensity of sunlight.[5]

Rice grains can be planted directly into the field where they will grow, or seedlings can be grown in a seedbed and transplanted into the field. Direct seeding needs some 60 to 80 kg of grain per hectare, while transplanting needs less, around 40 kg per hectare, but requires far more labour.[6] Most rice in Asia is transplanted by hand. Mechanical transplanting takes less time but requires a carefully-prepared field and seedlings raised on mats or in trays to fit the machine.[7]

Rice does not thrive if continuously submerged.[8] Rice can be grown in different environments, depending upon water availability. The usual arrangement is for lowland fields to be surrounded by bunds and flooded to a depth of a few centimetres until around a week before harvest time; this requires a large amount of water. The "alternate wetting and drying" technique uses less water. One form of this is to flood the field to a depth of 5 cm (2 in), then to let the water level drop to 15 cm (6 in) below surface level, as measured by looking into a perforated field water tube sunk into the soil, and then repeating the cycle.[9] Deepwater rice varieties tolerate flooding to a depth of over 50 centimetres for at least a month.[10] Upland rice is grown without flooding, in hilly or mountainous regions; it is rainfed like wheat or maize.[11]

Harvesting

Across Asia, unmilled rice or "paddy" (Indonesian and Malay *padi*), was traditionally the product of smallholder agriculture, with manual harvesting. Larger farms make use of machines such as combine harvesters to reduce the input of labour.[12] The grain is ready to harvest when the moisture content is 20–25%. Harvesting involves reaping, stacking the cut stalks, threshing to separate the grain, and cleaning by winnowing or screening.[13] The rice grain is dried as soon as possible to bring the moisture content down to a level that is safe from mould fungi. Traditional drying relies on the heat of the sun, with the grain spread out on mats or on pavements.[14]

Evolution

Phylogeny

Further information: Oryza sativa

The edible rice species are members of the BOP clade within the grass family, the Poaceae. The rice subfamily, Oryzoideae, is sister to the bamboos, Bambusoideae, and the cereal subfamily Pooideae. The rice genus *Oryza* is one of eleven in the Oryzeae; it is sister to the Phyllorachideae. The edible rice species *O. sativa* and *O. glaberrima* are among some 300 species or subspecies in the genus.[15]

History

Main article: History of rice cultivation

Oryza sativa rice was first domesticated in the Yangtze River basin in China 13,500 to 8,200 years ago.[16] The functional allele for nonshattering, the critical indicator of domestication in grains, as well as five other single-nucleotide polymorphisms, is identical in both *indica* and *japonica*. This implies a single domestication event for *O. sativa*.[17] Both *indica* and *japonica* forms of Asian rice sprang from a single domestication event in China from the wild rice *Oryza rufipogon*.[16][17] Despite this evidence, it appears that *indica* rice arose when *japonica* arrived in India about 4,500 years ago and hybridised with another rice, whether an undomesticated proto-*indica* or wild *O. nivara*.[18] Further, rice grains with signs of having been cut have been found alongside stone tools dated to 17,300 years ago at Sorori in Korea. This implies domestication in progress, far from the Yangtze River basin, at an earlier date.[19]

Cultivation, migration and trade spread rice around the world—first to much of east Asia, then further abroad, and eventually to the Americas as part of the Columbian exchange after 1492.[20] The now less common *Oryza glaberrima* (African rice) was independently domesticated in Africa around 3,000 years ago,[20] and introduced to the Americas by the Spanish.[21]

Commerce

Rice production – 2021	
Country	**Millions of tonnes**
China	213

India	195
Bangladesh	57
Indonesia	54
Vietnam	44
Thailand	30
World	**787**[22]

Production

See also: List of countries by rice production

In 2021, world production of rice was 787 million tonnes, led by China and India with a combined 52% of the total.[22] This placed rice fourth in the list of crops by production, after sugarcane, maize, and wheat.[23] Other major producers were Bangladesh, Indonesia and Vietnam.[23] 90% of world production is from Asia.[24]

Yield records

The average world yield for rice was 4.7 metric tons per hectare (2.1 short tons per acre), in 2022.[25] Yuan Longping of China's National Hybrid Rice Research and Development Center set a world record for rice yield in 1999 at 17.1 metric tons per hectare (7.6 short tons per acre) on a demonstration plot. This employed specially developed hybrid rice and the System of Rice Intensification (SRI), an innovation in rice farming.[26]

Food security

Rice is a major food staple in Asia, Latin America, and some parts of Africa,[27] feeding over half the world's population.[24] However, a substantial part of the crop can be lost post-harvest through inefficient transportation, storage, and milling. A quarter of the crop in Nigeria is lost after harvest. Storage losses include damage by mould fungi if the rice is not dried sufficiently. In China, losses in modern metal silos were just 0.2%, compared to 7–13% when rice was stored by rural households.[28]

Processing

The dry grain is milled to remove the outer layers, namely the husk and bran. These can be removed in a single step, in two steps, or as in commercial milling in a multi-step process of cleaning, dehusking, separation, polishing, grading, and weighing.[29] Brown rice only has the inedible husk removed.[30] Further milling removes bran and the germ to create successively whiter products.[30] Parboiled rice is subjected to a steaming process before it is milled. This makes the grain harder, and moves some of the grain's vitamins and minerals into the white part of the rice so these are retained after milling.[30] Rice does not contain gluten, so is suitable for people on a gluten-free diet.[31] Rice is a good source of protein and a staple food in many parts of the world, but it is not a complete protein as it does not contain all of the essential amino acids in sufficient amounts for good health.[32]

Trade

World trade figures are much smaller than those for production, as less than 8% of rice produced is traded internationally. China, an exporter of rice in the early 2000s, had become the world's largest importer of rice by 2013.[33] Developing countries are the main players in the world rice trade; by 2012, India was the largest exporter of rice, with Thailand and Vietnam the other largest exporters.[34]

Worldwide consumption

As of 2016, the countries that consumed the most rice were China (29% of total), India, and Indonesia.[35] By 2020, Bangladesh had taken third place from Indonesia. On an annual average from 2020-23, China consumed 154 million tonnes of rice, India consumed 109 million tonnes, and Bangladesh and Indonesia consumed about 36 million tonnes each. Across the world, rice consumption per capita fell in the 21st century as people in Asia and elsewhere ate less grain and more meat. An exception is Sub-Saharan Africa, where both per capita consumption of rice and population are increasing.[36]

Food

Nutritional value per 100 g (3.5 oz)	
Energy	544 kJ (130 kcal)
Carbohydrates	28.6 g
Fat	0.2 g

Protein	2.4 g

Vitamins	**Quantity**
	%DV†
Thiamine (B1)	2%
	0.02 mg
Riboflavin (B2)	2%
	0.02 mg
Niacin (B3)	3%
	0.4 mg
Pantothenic acid (B5)	8%
	0.41 mg
Vitamin B6	4%
	0.05 mg
Folate (B9)	1%
	2 μg

Minerals	Quantity
	%DV†
Calcium	0%
	3 mg
Iron	2%
	0.2 mg
Magnesium	4%
	13 mg
Manganese	18%
	0.38 mg
Phosphorus	5%
	37 mg
Potassium	1%
	29 mg
Sodium	0%
	0 mg
Zinc	4%
	0.4 mg

Other constituents	Quantity
Water	69 g

Main article: Rice as food

Eating qualities

Rice is a commonly-eaten food around the world. The varieties of rice are typically classified as short-, medium-, and long-grained. *Oryza sativa indica* varieties are usually long-grained; *Oryza sativa japonica* varieties are usually short- or medium-grained. Short-grain rice, with the exception of Spanish Bomba, is usually sticky when cooked, and is suitable for puddings. Thai Jasmine rice is aromatic, and unusually for a long-grain rice has some stickiness, with a soft texture. Indian Basmatic rice is very long-grained and aromatic. Italian Arborio rice, used for risotto, is of medium length, oval, and quite sticky. Japanese sushi rice is a sticky short-grain variety.[38]

Nutrition

Cooked white rice is 69% water, 29% carbohydrates, 2% protein, and contains negligible fat (table). In a reference serving of 100 grams (3.5 oz), cooked white rice provides 130 calories of food energy, and contains moderate levels of manganese (18% DV), with no other micronutrients in significant content (all less than 10% of the Daily Value).[39] In 2018, the World Health Organization strongly recommended fortifying rice with iron, and conditionally recommended fortifying it with vitamin A and with folic acid.[40]

Golden rice

Main article: Golden rice

Golden rice is a variety produced through genetic engineering to synthesize beta-carotene, a precursor of vitamin A, in the endosperm of the rice grain. It is intended to be grown and eaten in parts of the world where Vitamin A deficiency is prevalent.[41][42] Golden rice has been opposed by activists, such as in the Philippines.[43] In 2016 more than 100 Nobel laureates encouraged the use of genetically modified organisms, such as golden rice, for the benefits these could bring.[44]

Rice and climate change

Greenhouse gases from rice

In 2022, greenhouse gas emissions from rice cultivation were estimated at 5.7 billion tonnes CO2eq, representing 1.2% of total emissions.[45] Within the agriculture sector, rice produces almost half the greenhouse gas emissions from croplands,[46] some 30% of agricultural methane emissions, and 11% of agricultural nitrous oxide emissions.[47] Methane is released from rice fields subject to long-term flooding, as this inhibits the soil from absorbing atmospheric oxygen, resulting in anaerobic fermentation of organic matter in the soil.[48] Emissions can be limited by planting new varieties, not flooding continuously, and removing straw.[49]

Effect of global warming on rice

A 2010 study found that, as a result of rising temperatures and decreasing solar radiation during the later years of the 20th century, the rice yield, measured at over 200 farms in seven Asian countries, decreased by between 10% and 20%. This may be caused by increased night-time respiration.[50][51] IRRI has predicted that Asian rice yields will fall by some 20% per 1°C rise in global mean temperature. Further, rice is unable to yield grain if the flowers experience a temperature of 35°C or more for over one hour, so the crop would be lost under these conditions.[52][53]

In the Po Valley in Italy, the arborio and carnaroli risotto rice varieties have suffered poor harvests through drought in the 21st century. The Ente Nazionale Risi [it] is developing drought-resistant varieties; its *nuovo prometeo* variety has deep roots that enable it to tolerate drought, but is not suitable for risotto.[54]

Pests, weeds, and diseases

Pests and weeds

Rice yield can be reduced by weed growth, and a wide variety of pests including insects, nematodes, rodents such as rats, snails, and birds.[55] Major rice insect pests include ants, armyworms, black bugs, cutworms, field crickets, grasshoppers, leafhoppers, mealybugs, and planthoppers.[56] High rates of nitrogen fertilizer application may worsen aphid outbreaks.[57] Weather conditions can contribute to pest outbreaks: rice gall midge outbreaks are worsened by high rainfall in the wet season, while thrips outbreaks are associated with drought.[58]

Diseases

Rice blast, caused by the fungus *Magnaporthe grisea*, is the most serious disease of growing rice.[59] It and bacterial leaf streak (caused by *Xanthomonas oryzae* pv. *oryzae*) are perennially the two worst rice diseases worldwide; they are both among the ten most important diseases of all crop plants.[60] Other major rice diseases include sheath blight (caused by *Rhizoctonia solani*), false smut (*Ustilaginoidea virens*), and bacterial panicle blight (*Burkholderia glumae*).[60] Viral diseases include rice bunchy stunt, rice dwarf, rice tungro, and rice yellow mottle.[61]

Pest management

Further information: Integrated pest management and rice-duck farming

Crop protection scientists are developing sustainable techniques for managing rice pests.[62] Sustainable pest management is based on four principles: biodiversity, host plant resistance, landscape ecology, and hierarchies in a landscape—from biological to social.[63] Farmers' pesticide applications are often unnecessary.[64] Pesticides may actually induce resurgence of populations of rice pests such as planthoppers, both by destroying beneficial insects and by enhancing the pest's reproduction.[65] The International Rice Research Institute (IRRI) demonstrated in 1993 that an 87.5% reduction in pesticide use can lead to an overall drop in pest numbers.[66]

Farmers in China, Indonesia and the Philippines have traditionally managed weeds and pests by the polycultural practice of raising ducks and sometimes fish in their rice paddies. These produce valuable additional crops, eat small pest animals, manure the rice, and in the case of ducks also control weeds.[67][68]

Rice plants produce their own chemical defences to protect themselves from pest attacks. Some synthetic chemicals, such as the herbicide 2,4-D, cause the plant to increase the production of certain defensive chemicals and thereby increase the plant's resistance to some types of pests.[69] Conversely, other chemicals, such as the insecticide imidacloprid, appear to induce changes in the gene expression of the rice that make the plant more susceptible to certain
pests.[70]

Plant breeders have created rice cultivars incorporating resistance to various insect pests. Conventional plant breeding of resistant varieties has been limited by challenges such as rearing insect pests for testing, and the great diversity and continuous evolution of pests.

Resistance genes are being sought from wild species of rice, and genetic engineering techniques are being applied.[71]

Ecotypes and cultivars

The International Rice Research Institute maintains the International Rice Genebank, which holds over 100,000 rice varieties.[72][73] Much of southeast Asia grows sticky or glutinous rice varieties.[74] High-yield cultivars of rice suitable for cultivation in Africa, called the New Rice for Africa (NERICA), have been developed to improve food security and alleviate poverty in Sub-Saharan Africa.[75]

The complete genome of rice was sequenced in 2005, making it the first crop plant to reach this status.[76] Since then, the genomes of hundreds of types of rice, both wild and cultivated, and including both Asian and African rice species, have been sequenced.[77]

Biotechnology

High-yielding varieties

Main article: Green revolution

The high-yielding varieties are a group of crops created during the Green Revolution to increase global food production radically. The first Green Revolution rice variety, IR8, was produced in 1966 at the International Rice Research Institute through a cross between an Indonesian variety named "Peta" and a Chinese variety named "Dee Geo Woo Gen".[78] Green Revolution varieties were bred to have short strong stems so that the rice would not lodge or fall over. This enabled them to stay upright and productive even with heavy applications of fertilizer.[78]

Expression of human proteins

Ventria Bioscience has genetically modified rice to express lactoferrin and lysozyme which are proteins usually found in breast milk, and human serum albumin. These proteins have antiviral, antibacterial, and antifungal effects.[79] Rice containing these added proteins can be used as a component in oral rehydration solutions to treat diarrheal diseases, thereby shortening their duration and reducing recurrence. Such supplements may also help reverse anemia.[80]

Flood-tolerant rice

In areas subject to flooding, farmers have long planted flood tolerant varieties known as deepwater rice. In South and South East Asia, flooding affects some 20 million hectares (49 million acres) each year.[81] Flooding has historically led to massive losses in yields, such as in the Philippines, where in 2006, rice crops worth $65 million were lost to flooding.[82] Standard rice varieties cannot withstand stagnant flooding for more than about a week, since it disallows the plant access to necessary requirements such as sunlight and gas exchange. The Swarna Sub1 cultivar can tolerate week-long submergence, consuming carbohydrates efficiently and continuing to grow.[81]

Drought-tolerant rice

Drought represents a significant environmental stress for rice production, with 19–23 million hectares (47–57 million acres) of rainfed rice production in South and South East Asia often at risk.[83][84] Under drought conditions, without sufficient water to afford them the ability to obtain the required levels of nutrients from the soil, conventional commercial rice varieties can be severely affected—as happened for example in India early in the 21st century.[85]

The International Rice Research Institute conducts research into developing drought-tolerant rice varieties, including the varieties Sahbhagi Dhan, Sahod Ulan, and Sookha dhan, currently being employed by farmers in India, the Philippines, and Nepal respectively.[84] In addition, in 2013 the Japanese National Institute for Agrobiological Sciences led a team which successfully inserted the *DEEPER ROOTING 1* (*DRO1*) gene, from the Philippine upland rice variety Kinandang Patong, into the popular commercial rice variety IR64, giving rise to a far deeper root system in the resulting plants.[85] This facilitates an improved ability for the rice plant to derive its required nutrients in times of drought via accessing deeper layers of soil, a feature demonstrated by trials which saw the IR64 + DRO1 rice yields drop by 10% under moderate drought conditions, compared to 60% for the unmodified IR64 variety.[85][86]

Salt-tolerant rice

Soil salinity poses a major threat to rice crop productivity, particularly along low-lying coastal areas during the dry season.[83][87] For example, roughly 1 million hectares (2.5 million acres) of the coastal areas of Bangladesh are affected by saline soils.[88] These high concentrations of salt can severely affect rice plants' physiology, especially during early stages of growth, and as such farmers are often forced to abandon these areas.[89]

Progress has been made in developing rice varieties capable of tolerating such conditions; the hybrid created from the cross between the commercial rice variety IR56 and the wild rice species *Oryza coarctata* is one example.[90] *O. coarctata* can grow in soils with double the limit of salinity of normal varieties, but does not produce edible rice.[90] Developed by the International Rice Research Institute, the hybrid variety utilises specialised leaf glands that remove salt into the atmosphere. It was produced from one successful embryo out of 34,000 crosses between the two species; this was then backcrossed to IR56 with the aim of preserving the genes responsible for salt tolerance that were inherited from *O. coarctata*.[89]

Environment-friendly rice

Producing rice in paddies is harmful for the environment due to the release of methane by methanogenic bacteria. These bacteria live in the anaerobic waterlogged soil, consuming nutrients released by rice roots. Putting the barley gene *SUSIBA2* into rice creates a shift in biomass production from root to shoot, decreasing the methanogen population, and resulting in a reduction of methane emissions of up to 97%. Further, the modification increases the amount of rice grains.[91][92]

Model organism

Rice is used as a model organism for investigating the mechanisms of meiosis and DNA repair in higher plants.[93] For example, study using rice has shown that the gene *OsRAD51C* is necessary for the accurate repair of DNA double-strand breaks during meiosis.[94]

In human culture

Rice plays an important role in certain religions and popular beliefs. In Hindu wedding ceremonies, rice, denoting fertility, prosperity, and purity, is thrown into the sacred fire, a custom modified in Western weddings, where people throw rice.[95] In Malay weddings, rice features in multiple special wedding foods such as sweet glutinous rice.[96] In Japan and the Philippines, rice wine is used for weddings and other celebrations.[97] Dewi Sri is a goddess of the Indo-Malaysian archipelago, who in myth is transformed into rice or other crops.[98] The start of the rice planting season is marked in Asian countries including Nepal and Cambodia with a Royal Ploughing Ceremony.

Wheat is a grass widely cultivated for its seed, a cereal grain that is a worldwide staple food. The many species of wheat together make up the genus Triticum (/ˈtrɪtɪkəm/); the most widely grown is common wheat (T. aestivum). The archaeological record suggests that wheat was first cultivated in the regions of the Fertile Crescent around 9600 BC. Botanically, the wheat kernel is a caryopsis, a type of fruit.

Wheat is grown on more land area than any other food crop (220.7 million hectares or 545 million acres in 2021). World trade in wheat is greater than for all other crops combined. In 2021, world wheat production was 771 million tonnes (850 million short tons), making it the second most-produced cereal after maize (known as corn in the US and Australia; wheat is often called corn in other countries). Since 1960, world production of wheat and other grain crops has tripled and is expected to grow further through the middle of the 21st century. Global demand for wheat is increasing because of the usefulness of gluten to the food industry.

Wheat is an important source of carbohydrates. Globally, it is the leading source of vegetable proteins in human food, having a protein content of about 13%, which is relatively high compared to other major cereals but relatively low in protein quality (supplying essential amino acids). When eaten as the whole grain, wheat is a source of multiple nutrients and dietary fiber. In a small part of the general population, gluten – which comprises most of the protein in wheat – can trigger coeliac disease, noncoeliac gluten sensitivity, gluten ataxia, and dermatitis herpetiformis.

Description

A: Plant; B ripe ear of corn; 1 spikelet before flowering; 2 the same, flowering and spread, enlarged; 3 flowers with glumes; 4 stamens 5 pollen; 6 and 7 ovaries with juice scales; 8 and 9 parts of the scar; 10 fruit husks; 11, 12, 13 seeds, natural size and enlarged; 14 the same cut up,

enlarged.

Wheat is a stout grass of medium to tall height. Its stem is jointed and usually hollow, forming a straw. There can be many stems on one plant. It has long narrow leaves, their bases sheathing the stem, one above each joint. At the top of the stem is the flower head, containing some 20 to 100 flowers. Each flower contains both male and female parts. The flower, which is windpollinated, is housed in a pair of small leaflike glumes. The two (male) stamens and (female) stigmas protrude outside the glumes. The flowers are grouped into spikelets, each with between two and six flowers. Each fertilised carpel develops into a wheat grain or berry; botanically a fruit, it is often called a seed. The grains ripen to a golden yellow; a head of grain is called an ear.

Leaves emerge from the shoot apical meristem in a telescoping fashion until the transition to reproduction i.e. flowering. The last leaf produced by a wheat plant is known as the flag leaf. It is denser and has a higher photosynthetic rate than other leaves, to supply carbohydrate to the developing ear. In temperate countries the flag leaf, along with the second and third highest leaf on the plant, supply the majority of carbohydrate in the grain and their condition is paramount to yield formation. Wheat is unusual among plants in having more stomata on the upper (adaxial) side of the leaf, than on the under (abaxial) side. It has been theorised that this might be an effect of it having been domesticated and cultivated longer than any other plant. Winter wheat generally produces up to 15 leaves per shoot and spring wheat up to 9 and winter crops may have up to 35 tillers (shoots) per plant (depending on cultivar).

Wheat roots are among the deepest of arable crops, extending as far down as 2 metres (6 ft 7 in). While the roots of a wheat plant are growing, the plant also accumulates an energy store in its stem, in the form of fructans, which helps the plant to yield under drought and disease pressure, but it has been observed that there is a trade-off between root growth and stem nonstructural carbohydrate reserves. Root growth is likely to be prioritised in drought-adapted crops, while stem non-structural carbohydrate is prioritised in varieties developed for countries where disease is a bigger issue.

Depending on variety, wheat may be awned or not awned. Producing awns incurs a cost in grain number, but wheat awns photosynthesise more efficiently than their leaves with regards to water usage, so awns are much more frequent in varieties of wheat grown in hot drought-prone countries than those generally seen in temperate countries. For this reason, awned varieties could become more widely grown due to climate change. In Europe, however, a decline in climate resilience of wheat has been observed.

History

Origin and 21st century production areas of wheat

Domestication

Further information: Domestication

Hunter-gatherers in West Asia harvested wild wheats for thousands of years before they were domesticated, perhaps as early as 21,000 BC, but they formed a minor component of their diets. This phase of pre-domestication cultivation lasted at least a thousand years, during which early cultivars were spread around the region and slowly developed the traits that would come to characterise their domesticated forms.

Repeated harvesting and sowing of the grains of wild grasses led to the creation of domestic strains, as mutant forms ('sports') of wheat were more amenable to cultivation. In domesticated wheat, grains are larger, and the seeds (inside the spikelets) remain attached to the ear by a toughened rachis during harvesting. In wild strains, a more fragile rachis allows the ear to shatter easily, dispersing the spikelets. Selection for larger grains and non-shattering heads by farmers might not have been deliberately intended, but simply have occurred because these traits made gathering the seeds easier; nevertheless such 'incidental' selection was an important part of crop domestication. As the traits that improve wheat as a food source involve the loss of the plant's natural seed dispersal mechanisms, highly domesticated strains of wheat cannot survive in the wild.

Wild einkorn wheat (T. monococcum subsp. boeoticum) grows across Southwest Asia in open parkland and steppe environments. It comprises three distinct races, only one of which, native to Southeast Anatolia, was domesticated. The main feature that distinguishes domestic einkorn from wild is that its ears do not shatter without pressure, making it dependent on humans for dispersal and reproduction. It also tends to have wider grains. Wild einkorn was collected at sites such as Tell Abu Hureyra (c. 10,700–9000 BC) and Mureybet (c. 9800–9300 BC), but the earliest archaeological evidence for the domestic form comes after c. 8800 BC in southern Turkey, at Çayönü, Cafer Höyük, and possibly Nevalı Çori. Genetic evidence indicates that it was domesticated in multiple places independently.

Wild emmer wheat (T. turgidum subsp. dicoccoides) is less widespread than einkorn, favouring the rocky basaltic and limestone soils found in the hilly flanks of the Fertile Crescent. It is more diverse, with domesticated varieties falling into two major groups: hulled or non-shattering, in which threshing separates the whole spikelet; and free-threshing, where the individual grains are separated. Both varieties probably existed in prehistory, but over time free-threshing cultivars became more common. Wild emmer was first cultivated in the southern Levant, as early as 9600 BC. Genetic studies have found that, like einkorn, it was domesticated in southeastern Anatolia, but only once. The earliest secure archaeological evidence for domestic emmer comes from Çayönü, c. 8300–7600 BC, where distinctive scars on the spikelets indicated that they came from a hulled domestic variety. Slightly earlier finds have been reported from Tell Aswad in Syria, c. 8500–8200 BC, but these were identified using a less reliable method based on grain size.

Early farming

Sickles with stone microblades were used to harvest wheat in the Neolithic period, c. 8500– 4000 BC

Einkorn and emmer are considered two of the founder crops cultivated by the first farming societies in Neolithic West Asia. These communities also cultivated naked wheats (T. aestivum and T. durum) and a now-extinct domesticated form of Zanduri wheat (T. timopheevii), as well as a wide variety of other cereal and non-cereal crops. Wheat was relatively uncommon for the first thousand years of the Neolithic (when barley predominated), but became a staple after around 8500 BC. Early wheat cultivation did not demand much labour. Initially, farmers took advantage of wheat's ability to establish itself in annual grasslands by enclosing fields against grazing animals and re-sowing stands after they had been harvested, without the need to systematically remove vegetation or till the soil. They may also have exploited natural wetlands and floodplains to practice décrue farming, sowing seeds in the soil left behind by receding floodwater. It was harvested with stone-bladed sickles. The ease of storing wheat and other cereals led farming households to become gradually more reliant on it over time, especially after they developed individual storage facilities that were large enough to hold more than a year's supply.

Wheat grain was stored after threshing, with the chaff removed. It was then processed into flour using ground stone mortars. Bread made from ground einkorn and the tubers of a form of club rush

(Bolboschoenus glaucus) was made as early as 12,400 BC. At Çatalhöyük (c. 7100–6000 BC), both wholegrain wheat and flour was used to prepare bread, porridge and gruel. Apart from food, wheat may also have been important to Neolithic societies as a source of straw, which could be used for fuel, wicker-making, or wattle and daub construction.

Spread

Domestic wheat was quickly spread to regions where its wild ancestors did not grow naturally. Emmer was introduced to Cyprus as early as 8600 BC and einkorn c. 7500 BC; emmer reached Greece by 6500 BC, Egypt shortly after 6000 BC, and Germany and Spain by 5000 BC."The early Egyptians were developers of bread and the use of the oven and developed baking into one of the first large-scale food production industries." By 4000 BC, wheat had reached the British Isles and Scandinavia. Wheat likely appeared in China's lower Yellow River around 2600 BC.

The oldest evidence for hexaploid wheat has been confirmed through DNA analysis of wheat seeds, dating to around 6400–6200 BC, recovered from Çatalhöyük. As of 2023, the earliest known wheat with sufficient gluten for yeasted breads was found in a granary at Assiros in Macedonia dated to 1350 BC. From the Middle East, wheat continued to spread across Europe and to the Americas in the Columbian exchange. In the British Isles, wheat straw (thatch) was used for roofing in the Bronze Age, and remained in common use until the late 19th century. White wheat bread was historically a high status food, but during the nineteenth century it became in Britain an item of mass consumption, displacing oats, barley and rye from diets in the North of the country. It became "a sign of a high degree of culture". After 1860, the enormous expansion of wheat production in the United States flooded the world market, lowering prices by 40%, and (along with the expansion of potato growing) made a major contribution to the nutritional welfare of the poor.

Sumerian cylinder seal impression dating to c. 3200 BC showing an ensi and his acolyte feeding a sacred herd wheat stalks; Ninurta was an agricultural deity and, in a poem known as the "Sumerian Georgica", he offers detailed advice on farming

Sumerian cylinder seal impression dating to c. 3200 BC showing an ensi and his acolyte feeding a sacred herd wheat stalks; Ninurta was an agricultural deity and, in a poem known as the "Sumerian Georgica", he offers detailed advice on farming

Evolution

Phylogeny

Wheat origins by repeated hybridization and polyploidy. Not all species are shown.

Some wheat species are diploid, with two sets of chromosomes, but many are stable polyploids, with four sets of chromosomes (tetraploid) or six (hexaploid). Einkorn wheat (Triticum monococcum) is diploid (AA, two complements of seven chromosomes, 2n=14). Most tetraploid wheats (e.g. emmer and durum wheat) are derived from wild emmer, T. dicoccoides. Wild emmer is itself the result of a hybridization between two diploid wild grasses, T. urartu and a wild goatgrass such as Ae. speltoides. The hybridization that formed wild emmer (AABB, four complements of seven chromosomes in two groups, 4n=28) occurred in the wild, long before domestication, and was driven by natural selection. Hexaploid wheats evolved in farmers' fields as wild emmer hybridized with another goatgrass, Ae. squarrosa or Ae. tauschii, to make the hexaploid wheats including bread wheat.

A 2007 molecular phylogeny of the wheats gives the following not fully-resolved cladogram of major cultivated species; the large amount of hybridisation makes resolution difficult. Markings like "6N" indicate the degree of polyploidy of each species:

Taxonomy

During 10,000 years of cultivation, numerous forms of wheat, many of them hybrids, have developed under a combination of artificial and natural selection. This complexity and diversity of status has led to much confusion in the naming of wheats.

Major species

Hexaploid species (6N)

Common wheat or bread wheat (T. aestivum) – The most widely cultivated species in the world.

Spelt (T. spelta) – Another species largely replaced by bread wheat, but in the 21st century grown, often organically, for artisanal bread and pasta.

Tetraploid species (4N)

Durum (T. durum) – A wheat widely used today, and the second most widely cultivated wheat.

Emmer (T. turgidum subsp. dicoccum and T. t. conv. durum) – A species cultivated in ancient times, derived from wild emmer, T. dicoccoides, but no longer in widespread use.

Khorasan or Kamut (T. turgidum ssp. turanicum, also called T. turanicum) is an ancient grain type; Khorasan is a historical region in modern-day Afghanistan and the northeast of Iran. The grain is twice the size of modern wheat and has a rich nutty flavor.

Diploid species (2N)

Einkorn (T. monococcum). Domesticated from wild einkorn, T. boeoticum, at the same time as emmer wheat.

Hulled versus free-threshing species

Hulled wheat & Einkorn. Note how the einkorn ear breaks down into intact spikelets.

The four wild species of wheat, along with the domesticated varieties einkorn, emmer and spelt, have hulls. This more primitive morphology (in evolutionary terms) consists of toughened glumes that tightly enclose the grains, and (in domesticated wheats) a semi-brittle rachis that breaks easily on threshing. The result is that when threshed, the wheat ear breaks up into spikelets. To obtain the grain, further processing, such as milling or pounding, is needed to remove the hulls or husks. Hulled wheats are often stored as spikelets because the toughened glumes give good protection against pests of stored grain. In free-threshing (or naked) forms, such as durum wheat and common wheat, the glumes are fragile and the rachis tough. On threshing, the chaff breaks up, releasing the grains.

As a food

Naming of grain classes

Wheat grain classes are named by color, season, and hardness. The classes used in the United States are:

Durum – Hard, translucent, light-colored grain used to make semolina flour for pasta and bulghur; high in protein, specifically, gluten protein.

Hard Red Spring – Hard, brownish, high-protein wheat used for bread and hard baked goods. Bread flour and high-gluten flours are commonly made from hard red spring wheat. It is primarily traded on the Minneapolis Grain Exchange.

Hard Red Winter – Hard, brownish, mellow high-protein wheat used for bread, hard baked goods and as an adjunct in other flours to increase protein in pastry flour for pie crusts. Some brands of unbleached all-purpose flours are commonly made from hard red winter wheat alone. It is primarily traded on the Kansas City Board of Trade. Many varieties grown from Kansas south are descendant from a variety known as "turkey red", which was brought to Kansas by Mennonite immigrants from Russia. Marquis wheat was developed to prosper in the shorter growing season in Canada, and is grown as far south as southern Nebraska.

Soft Red Winter – Soft, low-protein wheat used for cakes, pie crusts, biscuits, and muffins. Cake flour, pastry flour, and some self-rising flours with baking powder and salt added, for example, are made from soft red winter wheat. It is primarily traded on the Chicago Board of Trade.

Hard White – Hard, light-colored, opaque, chalky, medium-protein wheat planted in dry, temperate areas. Used for bread and brewing.

Soft White – Soft, light-colored, very low protein wheat grown in temperate moist areas. Used for pie crusts and pastry.

Food value and uses

Wheat is used in a wide variety of foods.

Wheat, hard red winter

Nutritional value per 100 g (3.5 oz)

Energy 1,368 kJ (327 kcal)

Carbohydrates

71.18 g

Sugars 0.41
Dietary fiber 12.2 g

Fat

1.54 g

Protein

12.61 g

Vitamins Quantity%DV†

Thiamine (B1) 33%0.383 mg

Riboflavin (B2) 10%0.115 mg

Niacin (B3) 5.464 mg

Pantothenic acid (B5) 19%0.954 mg
Vitamin B6 23%0.3 mg

Folate (B9) 10%38 μg

Choline 6%31.2 mg

Vitamin E 7%1.01 mg

Vitamin K 2%1.9 μg

Minerals Quantity%DV†

Calcium 3%29 mg

Iron 25%3.19 mg
Magnesium 35%126 mg

Manganese 190%3.985 mg

Phosphorus 41%288 mg

Potassium 12%363 mg

Sodium 0%2 mg
Zinc 28%2.65 mg

Other constituents Quantity

Water 13.1 g

Selenium	70.7 µg

Link to USDA Database Entry Units

µg = micrograms • mg = milligrams

IU = International units

†Percentages are roughly approximated using US recommendations for adults.

Source: USDA FoodData Central

Wheat is a staple cereal worldwide. Raw wheat berries can be ground into flour or, using hard durum wheat only, can be ground into semolina; germinated and dried creating malt; crushed or cut into cracked wheat; parboiled (or steamed), dried, crushed and de-branned into bulgur also known as groats. If the raw wheat is broken into parts at the mill, as is usually done, the outer husk or bran can be used in several ways. Wheat is a major ingredient in such foods as bread, porridge, crackers, biscuits, muesli, pancakes, pasta, pies, pastries, pizza, semolina, cakes, cookies, muffins, rolls, doughnuts, gravy, beer, vodka, boza (a fermented beverage), and breakfast cereals. In manufacturing wheat products, gluten is valuable to impart viscoelastic functional qualities in dough, enabling the preparation of diverse processed foods such as breads, noodles, and pasta that facilitate wheat consumption.

Nutrition

Raw red winter wheat is 13% water, 71% carbohydrates including 12% dietary fiber, 13% protein, and 2% fat (table). Some 75–80% of the protein content is as gluten. In a reference amount of 100 grams (3.5 oz), wheat provides 1,368 kilojoules (327 kilocalories) of food energy and is a rich source (20% or more of the Daily Value, DV) of multiple dietary minerals, such as manganese, phosphorus, magnesium, zinc, and iron (table). The B vitamins, niacin (36% DV), thiamine (33% DV), and vitamin B6 (23% DV), are present in significant amounts (table).

Wheat is a significant source of vegetable proteins in human food, having a relatively high protein content compared to other major cereals. However, wheat proteins have a low quality for human nutrition, according to the DIAAS protein quality evaluation method. Though they contain adequate amounts of the other essential amino acids, at least for adults, wheat proteins are deficient in the essential amino acid lysine. Because the proteins present in the wheat endosperm (gluten proteins) are particularly poor in lysine, white flours are more deficient in lysine compared with whole grains. Significant efforts in plant breeding are made to develop lysine-rich wheat varieties, without success, as of 2017. Supplementation with proteins from other food sources (mainly legumes) is commonly used to compensate for this deficiency, since the limitation of a single essential amino acid causes the others to break down and become excreted, which is especially important during growth.

Health advisories

Consumed worldwide by billions of people, wheat is a significant food for human nutrition, particularly in the least developed countries where wheat products are primary foods. When eaten as the whole grain, wheat supplies multiple nutrients and dietary fiber recommended for children and adults. In genetically susceptible people, wheat gluten can trigger coeliac disease. Coeliac disease affects about 1% of the general population in developed countries. The only known effective treatment is a strict lifelong gluten-free diet. While coeliac disease is caused by a reaction to wheat proteins, it is not the same as a wheat allergy. Other diseases triggered by eating wheat are non-coeliac gluten sensitivity (estimated to affect 0.5% to 13% of the general population), gluten ataxia, and dermatitis herpetiformis. Certain short-chain carbohydrates present in wheat, known as FODMAPs (mainly fructose polymers), may be the cause of noncoeliac gluten sensitivity. As of 2019, reviews have concluded that FODMAPs only explain certain gastrointestinal symptoms, such as bloating, but not the extra-digestive symptoms that people with non-coeliac gluten sensitivity may develop health disorders. Other wheat proteins, amylase-trypsin inhibitors, have been identified as the possible activator of the innate immune system in coeliac disease and non-coeliac gluten sensitivity. These proteins are part of the plant's natural defence against insects and may cause intestinal inflammation in humans.

Production and consumption

Global

Wheat production, 2021

Country	Millions of tonnes
China	136.9
India	109.6
Russia	78.1
United States	44.8
France	36.6
Ukraine	32.2
Pakistan	27.5
World	771

In 2021, world wheat production was 771 million tonnes, led by China, India, and Russia which collectively provided 42% of the world total. As of 2019, the largest exporters were Russia (32 million tonnes), United States (27), Canada (23) and France (20), while the largest importers were Indonesia (11 million tonnes), Egypt (10.4) and Turkey (10.0). In 2021, wheat was grown on 220.7 million hectares or 545 million acres worldwide, more than any other food crop. World trade in wheat is greater than for all other crops combined. Global demand for wheat is increasing due to the unique viscoelastic and adhesive properties of gluten proteins, which facilitate the production of processed foods, whose consumption is increasing as a result of the worldwide industrialization process and westernization of diets.

Historical factors

Wheat prices in England, 1264–1996

Wheat became a central agriculture endeavor in the worldwide British Empire in the 19th century, and remains of great importance in Australia, Canada and India. In Australia, with vast lands and a limited work force, expanded production depended on technological advances, especially regarding irrigation and machinery. By the 1840s there were 900 growers in South Australia. They used "Ridley's Stripper", to remove the heads of grain, a reaper-harvester perfected by John Ridley in 1843. In Canada, modern farm implements made large scale wheat farming possible from the late 1840s. By 1879, Saskatchewan was the center, followed by Alberta, Manitoba and Ontario, as the spread of railway lines allowed easy exports to Britain. By 1910, wheat made up 22% of Canada's exports, rising to 25% in 1930 despite the sharp decline in prices during the worldwide Great Depression. Efforts to expand wheat production in South Africa, Kenya and India were stymied by low yields and disease. However, by 2000 India had become the second largest producer of wheat in the world. In the 19th century the American wheat frontier moved rapidly westward. By the 1880s 70% of American exports went to British ports. The first successful grain elevator was built in Buffalo in 1842. The cost of transport fell rapidly. In 1869 it cost 37 cents to transport a bushel of wheat from Chicago to Liverpool. In 1905 it was 10 cents.

In the 20th century, global wheat output expanded by about 5-fold, but until about 1955 most of this reflected increases in wheat crop area, with lesser (about 20%) increases in crop yields per unit area. After 1955 however, there was a ten-fold increase in the rate of wheat yield improvement per year, and this became the major factor allowing global wheat production to increase. Thus technological innovation and scientific crop management with synthetic nitrogen fertilizer, irrigation and wheat breeding were the main drivers of wheat output growth in the second half of the century. There were some significant decreases in wheat crop area, for instance in North America. Better seed storage and germination ability (and hence a smaller requirement to retain harvested crop for next year's seed) is another 20th-century technological innovation. In Medieval England, farmers saved one-quarter of their wheat harvest as seed for the next crop, leaving only three-quarters for food and feed consumption. By 1999, the global average seed use of wheat was about 6% of output. In the 21st century, rising temperatures associated with global warming are reducing wheat yield in several locations.

Peak wheat

Food production per person increased since 1961.

Peak wheat is the concept that agricultural production, due to its high use of water and energy inputs, is subject to the same profile as oil and other fossil fuel production. The central tenet is that a point is reached, the "peak", beyond which agricultural production plateaus and does not grow any further, and may even go into permanent decline.

Based on current supply and demand factors for agricultural commodities (e.g., changing diets in the emerging economies, biofuels, declining acreage under irrigation, growing global population, stagnant agricultural productivity growth), some commentators are predicting a long-term annual production shortfall of around 2% which, based on the highly inelastic demand curve for food crops, could lead to sustained price increases in excess of 10% a year – sufficient to double crop prices in seven years.

According to the World Resources Institute, global per capita food production has been increasing substantially for the past several decades.

Agronomy

Growing wheat

Wheat is an annual crop. It can be planted in autumn and harvested in early summer as winter wheat in climates that are not too severe, or planted in spring and harvested in autumn as spring wheat. It is normally planted after tilling the soil by ploughing and then harrowing to kill weeds and create an even surface. The seeds are then scattered on the surface, or drilled into the soil in rows. Winter wheat lies dormant during a winter freeze. It needs to develop to a height of 10 to 15 cm before the cold intervenes, so as to be able to survive the winter; it requires a period with the temperature at or near freezing, its dormancy then being broken by the thaw or rise in temperature. Spring wheat does not undergo dormancy. Wheat requires a deep soil, preferably a loam with organic matter, and available minerals including soil nitrogen, phosphorus, and potassium. An acid and peaty soil is not suitable. Wheat needs some 30 to 38 cm of rain in the growing season to form a good crop of grain.

The farmer may intervene while the crop is growing to add fertilizer, water by irrigation, or pesticides such as herbicides to kill broad-leaved weeds or insecticides to kill insect pests. The farmer may assess soil minerals, soil water, weed growth, or the arrival of pests to decide timely and cost-effective corrective actions, and crop ripeness and water content to select the right moment to harvest. Harvesting involves reaping, cutting the stems to gather the crop; and threshing, breaking the ears to release the grain; both steps are carried out by a combine harvester. The grain is then dried so that it can be stored safe from mould fungi.

Crop development

Wheat developmental stages on the BBCH and Zadok's scales

Wheat normally needs between 110 and 130 days between sowing and harvest, depending upon climate, seed type, and soil conditions. Optimal crop management requires that the farmer have a detailed understanding of each stage of development in the growing plants. In particular, spring fertilizers, herbicides, fungicides, and growth regulators are typically applied only at specific stages of plant development. For example, it is currently recommended that the second application of nitrogen is best done when the ear (not visible at this stage) is about 1 cm in size (Z31 on Zadoks scale). Knowledge of stages is also important to identify periods of higher risk from the climate. Farmers benefit from knowing when the 'flag leaf' (last leaf) appears, as this leaf represents about 75% of photosynthesis reactions during the grain filling period, and so should be preserved from disease or insect attacks to ensure a good yield. Several systems exist to identify crop stages, with the

Feekes and Zadoks scales being the most widely used. Each scale is a standard system which describes successive stages reached by the crop during the agricultural season. For example, the stage of pollen formation from the mother cell, and the stages between anthesis and maturity, are susceptible to high temperatures, and this adverse effect is made worse by water stress.

Farming techniques

Technological advances in soil preparation and seed placement at planting time, use of crop rotation and fertilizers to improve plant growth, and advances in harvesting methods have all combined to promote wheat as a viable crop. When the use of seed drills replaced broadcasting sowing of seed in the 18th century, another great increase in productivity occurred. Yields of pure wheat per unit area increased as methods of crop rotation were applied to land that had long been in cultivation, and the use of fertilizers became widespread.

Improved agricultural husbandry has more recently included pervasive automation, starting with the use of threshing machines, and progressing to large and costly machines like the combine harvester which greatly increased productivity. At the same time, better varieties such as Norin 10 wheat, developed in Japan in the 1930s, or the dwarf wheat developed by Norman Borlaug in the Green Revolution, greatly increased yields.

In addition to gaps in farming system technology and knowledge, some large wheat grainproducing countries have significant losses after harvest at the farm and because of poor roads, inadequate storage technologies, inefficient supply chains and farmers' inability to bring the produce into retail markets dominated by small shopkeepers. Some 10% of total wheat production is lost at farm level, another 10% is lost because of poor storage and road networks, and additional amounts are lost at the retail level.

In the Punjab region of the Indian subcontinent, as well as North China, irrigation has been a major contributor to increased grain output. More widely over the last 40 years, a massive increase in fertilizer use together with the increased availability of semi-dwarf varieties in developing countries, has greatly increased yields per hectare. In developing countries, use of (mainly nitrogenous) fertilizer increased 25-fold in this period. However, farming systems rely on much more than fertilizer and breeding to improve productivity. A good illustration of this is Australian wheat growing in the southern winter cropping zone, where, despite low rainfall (300 mm), wheat cropping is successful even with relatively little use of nitrogenous fertilizer. This is achieved by crop rotation with leguminous pastures. The inclusion of a canola crop in the rotations has boosted wheat yields by a further 25%. In these low rainfall areas, better use of available soil-water (and better control of soil erosion) is achieved by retaining the stubble after harvesting and by minimizing tillage.

Pests and diseases

Pests – or pests and diseases, depending on the definition – consume 21.47% of the world's wheat crop annually.

Diseases

Rust-affected wheat seedlings

There are many wheat diseases, mainly caused by fungi, bacteria, and viruses. Plant breeding to develop new disease-resistant varieties, and sound crop management practices are important for preventing disease. Fungicides, used to prevent the significant crop losses from fungal disease, can be a significant variable cost in wheat production. Estimates of the amount of wheat production lost owing to plant diseases vary between 10 and 25% in Missouri. A wide range of organisms infect wheat, of which the most important are viruses and fungi.

The main wheat-disease categories are:

Seed-borne diseases: these include seed-borne scab, seed-borne Stagonospora (previously known as Septoria), common bunt (stinking smut), and loose smut. These are managed with fungicides.

Leaf- and head- blight diseases: Powdery mildew, leaf rust, Septoria tritici leaf blotch, Stagonospora (Septoria) nodorum leaf and glume blotch, and Fusarium head scab.

Crown and root rot diseases: Two of the more important of these are 'take-all' and Cephalosporium stripe. Both of these diseases are soil borne.

Stem rust diseases: Caused by Puccinia graminis f. sp. tritici (basidiomycete) fungi e.g. ug99 Wheat

blast: Caused by Magnaporthe oryzae Triticum.

Viral diseases: Wheat spindle streak mosaic (yellow mosaic) and barley yellow dwarf are the two most common viral diseases. Control can be achieved by using resistant varieties.

A historically significant disease of cereals including wheat, though commoner in rye is ergot; it is unusual among plant diseases in also causing sickness in humans who ate grain contaminated with the fungus involved, Claviceps purpurea.

Animal pests

Pupa of the wheat weevil, Sitophilus granarius, inside a wheat kernel

Among insect pests of wheat is the wheat stem sawfly, a chronic pest in the Northern Great Plains of the United States and in the Canadian Prairies. Wheat is the food plant of the larvae of some Lepidoptera (butterfly and moth) species including the flame, rustic shoulder-knot, setaceous Hebrew character and turnip moth. Early in the season, many species of birds and rodents feed upon wheat crops. These animals can cause significant damage to a crop by digging up and eating newly planted seeds or young plants. They can also damage the crop late in the season by eating the grain from the mature spike. Recent post-harvest losses in cereals amount to billions of dollars per year in the United States alone, and damage to wheat by various borers, beetles and weevils is no exception. Rodents can also cause major losses during storage, and in major grain growing regions, field mice numbers can sometimes build up explosively to plague proportions because of the ready availability of food. To reduce the amount of wheat lost to post-harvest pests, Agricultural Research Service scientists have developed an "insect-o-graph", which can detect insects in wheat that are not visible to the naked eye. The device uses electrical signals to detect the insects as the wheat is being milled. The new technology is so precise that it can detect 5–10 infested seeds out of 30,000 good ones.

Breeding objectives

In traditional agricultural systems, wheat populations consist of landraces, informal farmermaintained populations that often maintain high levels of morphological diversity. Although landraces of wheat are no longer extensively grown in Europe and North America, they continue to be important elsewhere. The origins of formal wheat breeding lie in the nineteenth century, when single line varieties were created through selection of seed from a single plant noted to have desired properties. Modern wheat breeding developed in the first years of the twentieth century and was closely linked to the development of Mendelian genetics. The standard method of breeding inbred wheat cultivars is by crossing two lines using hand emasculation, then selfing or inbreeding the progeny. Selections are identified (shown to have the genes responsible for the varietal differences) ten or more generations before release as a variety or cultivar.

Major breeding objectives include high grain yield, good quality, disease- and insect resistance and tolerance to abiotic stresses, including mineral, moisture and heat tolerance. Wheat has been the subject of mutation breeding, with the use of gamma-, x-rays, ultraviolet light (collectively, radiation breeding), and sometimes harsh chemicals. The varieties of wheat created through these methods are in the hundreds (going as far back as 1960), more of them being created in higher populated countries such as China. Bread wheat with high grain iron and zinc content has been developed through gamma radiation breeding, and through conventional selection breeding. International wheat breeding is led by the International Maize and Wheat Improvement Center in Mexico. ICARDA is another major public sector international wheat breeder, but it was forced to relocate from Syria to Lebanon in the Syrian Civil War.

Pathogens and wheat are in a constant process of coevolution. Spore-producing wheat rusts are substantially adapted towards successful spore propagation, which is essentially to say its R0. These pathogens tend towards high-R0 evolutionary attractors.

For higher yields

Breeding has increased yields over time

The presence of certain versions of wheat genes has been important for crop yields. Genes for the 'dwarfing' trait, first used by Japanese wheat breeders to produce Norin 10 short-stalked wheat, have had a huge effect on wheat yields worldwide, and were major factors in the success of the Green

Revolution in Mexico and Asia, an initiative led by Norman Borlaug. Dwarfing genes enable the carbon that is fixed in the plant during photosynthesis to be diverted towards seed production, and they also help prevent the problem of lodging. "Lodging" occurs when an ear stalk falls over in the wind and rots on the ground, and heavy nitrogenous fertilization of wheat makes the grass grow taller and become more susceptible to this problem. By 1997, 81% of the developing world's wheat area was planted to semi-dwarf wheats, giving both increased yields and better response to nitrogenous fertilizer.

T. turgidum subsp. polonicum, known for its longer glumes and grains, has been bred into main wheat lines for its grain size effect, and likely has contributed these traits to Triticum petropavlovskyi and the Portuguese landrace group Arrancada. As with many plants, MADS-box influences flower development, and more specifically, as with other agricultural Poaceae, influences yield. Despite that importance, as of 2021 little research has been done into MADSbox and other such spikelet and flower genetics in wheat specifically.

The world record wheat yield is about 17 tonnes per hectare (15,000 pounds per acre), reached in New Zealand in 2017. A project in the UK, led by Rothamsted Research has aimed to raise wheat yields in the country to 20 t/ha (18,000 lb/acre) by 2020, but in 2018 the UK record stood at 16 t/ha (14,000 lb/acre), and the average yield was just 8 t/ha (7,100 lb/acre).

For disease resistance

Different strains have been infected with the stem rust fungus. The strains bred to be resistant have their leaves unaffected or relatively unaffected by the fungus.

Wild grasses in the genus Triticum and related genera, and grasses such as rye have been a source of many disease-resistance traits for cultivated wheat breeding since the 1930s. Some resistance genes have been identified against Pyrenophora tritici-repentis, especially races 1 and 5, those most problematic in Kazakhstan. Wild relative, Aegilops tauschii is the source of several genes effective against TTKSK/Ug99 - Sr33, Sr45, Sr46, and SrTA1662 - of which Sr33 and SrTA1662 are the work of Olson et al., 2013, and Sr45 and Sr46 are also briefly reviewed therein.

Lr67 is an R gene, a dominant negative for partial adult resistance discovered and molecularly characterized by Moore et al., 2015. As of 2018 Lr67 is effective against all races of leaf, stripe, and stem rusts, and powdery mildew (Blumeria graminis). This is produced by a mutation of two amino acids in what is predicted to be a hexose transporter. The product then heterodimerizes with the susceptible's product, with the downstream result of reducing glucose uptake.

Lr34 is widely deployed in cultivars due to its abnormally broad effectiveness, conferring resistance against leaf- and stripe-rusts, and powdery mildew. Krattinger et al. 2009 finds Lr34 to also be an ABC transporter and conclude that this is the probably means of its effectiveness and the reason that it produces a 'slow rusting'/adult resistance phenotype.

Pm8 is a widely used powdery mildew resistance introgressed from rye (Secale cereale). It comes from the rye 1R chromosome, a source of many resistances since the 1960s.

Resistance to Fusarium head blight (FHB, Fusarium ear blight) is also an important breeding target. Marker-assisted breeding panels involving kompetitive allele specific PCR can be used. Singh et al. 2019 identify a KASP genetic marker for a pore-forming toxin-like gene providing FHB resistance.

To create hybrid vigor

Because wheat self-pollinates, creating hybrid seed to provide the possible benefits of heterosis, hybrid vigor (as in the familiar F1 hybrids of maize), is extremely labor-intensive; the high cost of hybrid wheat seed relative to its moderate benefits have kept farmers from adopting them widely despite nearly 90 years of effort. Commercial hybrid wheat seed has been produced using chemical hybridizing agents, plant growth regulators that selectively interfere with pollen development, or naturally occurring cytoplasmic male sterility systems. Hybrid wheat has been a limited commercial success in Europe (particularly France), the United States and South Africa.

Synthetic hexaploids made by crossing the wild goatgrass wheat ancestor Aegilops tauschii, and other Aegilops, and various durum wheats are now being deployed, and these increase the genetic diversity of cultivated wheats.

For gluten content

Modern bread wheat varieties have been cross-bred to contain greater amounts of gluten, which affords significant advantages for improving the quality of breads and pastas from a functional point of view. However, a 2020 study that grew and analyzed 60 wheat cultivars from between 1891 and 2010 found no changes in albumin/globulin and gluten contents over time. "Overall, the harvest year had a more significant effect on protein composition than the cultivar. At the protein level, we found no evidence to support an increased immunostimulatory potential of modern winter wheat."

For water efficiency

Stomata (or leaf pores) are involved in both uptake of carbon dioxide gas from the atmosphere and water vapor losses from the leaf due to water transpiration. Basic physiological investigation of these gas exchange processes has yielded carbon isotope based method used for breeding wheat varieties with improved water-use efficiency. These varieties can improve crop productivity in rain-fed dry-land wheat farms.

For insect resistance

The gene Sm1 protects against the orange wheat blossom midge.

Genomics

Decoding the genome

In 2010, 95% of the genome of Chinese Spring line 42 wheat was decoded. This genome was released in a basic format for scientists and plant breeders to use but was not fully annotated. In 2012, an essentially complete gene set of bread wheat was published. Random shotgun libraries of total DNA and cDNA from the T. aestivum cv. Chinese Spring (CS42) were sequenced to generate 85 Gb of sequence (220 million reads) and identified between 94,000 and 96,000 genes. In 2018, a more complete Chinese Spring genome was released by a different team. In 2020, 15 genome sequences from various locations and varieties around the world were reported, with examples of their own use of the sequences to localize particular insect and disease resistance factors. Wheat Blast Resistance is controlled by R genes which are highly race-specific.

Genetic engineering

For decades, the primary genetic modification technique has been non-homologous end joining (NHEJ). However, since its introduction, the CRISPR/Cas9 tool has been extensively adopted, for example:

To intentionally damage three homologs of TaNP1 (a glucose-methanol-choline oxidoreductase gene) to produce a novel male sterility trait, by Li et al. 2020

Blumeria graminis f.sp. tritici resistance has been produced by Shan et al. 2013 and Wang et al. 2014 by editing one of the mildew resistance locus o genes (more specifically one of the Triticum aestivum MLO (TaMLO) genes)

Triticum aestivum EDR1 (TaEDR1) (the EDR1 gene, which inhibits Bmt resistance) has been knocked out by Zhang et al. 2017 to improve that resistance

Triticum aestivum HRC (TaHRC) has been disabled by Su et al. 2019 thus producing Gibberella zeae resistance.

Triticum aestivum Ms1 (TaMs1) has been knocked out by Okada et al. 2019 to produce another novel male sterility and Triticum aestivum acetolactate synthase (TaALS) and Triticum aestivum acetyl-CoAcarboxylase (TaACC) were subjected to base changes by Zhang et al. 2019 (in two publications) to confer herbicide resistance to ALS inhibitors and ACCase inhibitors respectively

As of 2021 these examples illustrate the rapid deployment and results that CRISPR/Cas9 has shown in wheat disease resistance improvement.

In art

Wheatfield with Crows, an 1890 painting by Vincent van Gogh. Van Gogh Museum, Amsterdam

The Dutch artist Vincent van Gogh created the series Wheat Fields between 1885 and 1890, consisting of dozens of paintings made mostly in different parts of rural France. They depict wheat crops, sometimes with farm workers, in varied seasons and styles, sometimes green, sometimes at harvest. Wheatfield with Crows was one of his last paintings, and is considered to be among his greatest works.

In 1967, the American artist Thomas Hart Benton made his oil on wood painting Wheat, showing a row of uncut wheat plants, occupying almost the whole height of the painting, between rows of freshly-cut stubble. The painting is held by the Smithsonian American Art Museum.

In 1982, the American conceptual artist Agnes Denes grew a two-acre field of wheat at Battery Park, Manhattan. The ephemeral artwork has been described as an act of protest. The harvested wheat was divided and sent to 28 world cities for an exhibition entitled "The International Art Show for the End of World Hunger".

Sugarcane

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For the EP by Tiwa Savage, see Sugarcane (EP). For the songs, see Sugarcane (Camidoh song) and Sugarcane (New Order song).

Saccharum officinarum

Sugarcane or sugar cane is a species of tall, perennial grass (in the genus Saccharum, tribe Andropogoneae) that is used for sugar production. The plants are 2–6 m (6–20 ft) tall with stout, jointed, fibrous stalks that are rich in sucrose,[1] which accumulates in the stalk internodes. Sugarcanes belong to the grass family, Poaceae, an economically important flowering plant family that includes maize, wheat, rice, and sorghum, and many forage crops. It is native to the warm temperate and tropical regions of India, Southeast Asia, and New Guinea.

Sugarcane was an ancient crop of the Austronesian and Papuan people. It was introduced to Polynesia, Island Melanesia, and Madagascar in prehistoric times via Austronesian sailors. It was also introduced to southern China and India by Austronesian traders around 1200 to 1000 BC. The Persians and Greeks encountered the famous "reeds that produce honey without bees" in India between the sixth and fourth centuries BC. They adopted and then spread sugarcane agriculture.[2] Merchants began to trade in sugar, which was considered a luxurious and expensive spice, from India. In the 18th century, sugarcane plantations began in the Caribbean, South American, Indian Ocean, and Pacific island nations. The need for sugar crop laborers became a major driver of large migrations, some people voluntarily accepting indentured servitude[3] and others forcibly imported as slaves.[4]

Grown in tropical and subtropical regions, sugarcane is the world's largest crop by production quantity, totaling 1.9 billion tonnes in 2020, with Brazil accounting for 40% of the world total. Sugarcane accounts for 79% of sugar produced globally (most of the rest is made from sugar beets). About 70% of the sugar produced comes from Saccharum officinarum and its hybrids.[5] All sugarcane species can interbreed, and the major commercial cultivars are complex hybrids.[6]

White sugar is produced from sugarcane in specialized mill factories. Sugarcane reeds are used to make pens, mats, screens, and thatch. The young, unexpanded flower head of Saccharum edule (duruka) is eaten raw, steamed, or toasted, and prepared in various ways in Southeast Asia, such as certain island communities of Indonesia as well as in Oceanic countries like Fiji.[7] The direct use of sugar cane to produce ethanol for biofuel is projected to potentially surpass the production of white sugar as an end product.

Etymology

The term 'sugarcane' is a combination of two words; sugar and cane. The former ultimately derives from Sanskrit शर्करा (śárkarā) as the crop originated in Southeast Asia. As sugar was traded and spread West, this became سُكَّر (sukkar) in Arabic, zúcchero in Italian, zuccarum in Latin, and eventually sucre in both Middle French and Middle English. The second term "cane" began to be used alongside it as the crop was grown on plantations in the Caribbean; gana is the Hindi word for sugarcane (gana = cane).[citation needed]

Characteristics

Sugarcane is one of the most widely produced primary crops in the world

Sugarcane, a perennial tropical grass, exhibits a unique growth pattern characterized by lateral shoots emerging at its base, leading to the development of multiple stems. These stems typically attain a height of 3 to 4 meters (approximately 10 to 13 feet) and possess a diameter of about 5 centimeters (approximately 2 inches). As these stems mature, they evolve into cane stalks, constituting a substantial portion of the entire plant, accounting for roughly 75% of its composition.[citation needed]

A fully mature cane stalk generally comprises a composition of around 11–16% fiber, 12–16% soluble sugars, 2–3% nonsugar carbohydrates, and 63–73% water content. The successful cultivation of sugarcane hinges on a delicate interplay of several factors, including climatic conditions, soil properties, irrigation methods, fertilization practices, pest and disease management, the selection of specific varieties, and the timing of the harvest.[citation needed]

In terms of yield, the average production of cane stalk stands at 60–70 tonnes per hectare (equivalent to 24–28 long tons per acre or 27–31 short tons per acre) annually. However, this yield figure is not fixed and can vary significantly, ranging from 30 to 180 tonnes per hectare. This variance is contingent upon the level of knowledge applied and the approach to crop management embraced in the cultivation of sugarcane. Ultimately, the successful cultivation of this valuable crop demands a thoughtful integration of various factors to optimize its growth and productivity.[citation needed]

Sugarcane is a cash crop, but it is also used as livestock fodder.[8] Sugarcane genome is one of the most complex plant genomes known, mostly due to interspecific hybridization and polyploidization.[9][10]

Cut sugarcane Cut

sugarcane

Sugarcane canopy

Sugarcane canopy

History

See also: Domesticated plants and animals of Austronesia and History of sugar

The two centers of domestication for sugarcane are one for Saccharum officinarum by Papuans in New Guinea and another for Saccharum sinense by Austronesians in Taiwan and southern China. Papuans and Austronesians originally primarily used sugarcane as food for domesticated pigs. The spread of both S. officinarum and S. sinense is closely linked to the migrations of the Austronesian peoples. Saccharum barberi was only cultivated in India after the introduction of S. officinarum.[11][12]

Map showing centers of origin of Saccharum officinarum in New Guinea, S. sinensis in southern China and Taiwan, and S. barberi in India; dotted arrows represent Austronesian introductions[13]

S. officinarum was first domesticated in New Guinea and the islands east of the Wallace Line by Papuans, where it is the modern center of diversity. Beginning around 6,000 BP, several strains were selectively bred from the native Saccharum robustum. From New Guinea, it spread westwards to Maritime Southeast Asia after contact with Austronesians, where it hybridized with Saccharum spontaneum.[12]

The second domestication center is mainland southern China and Taiwan, where S. sinense was a primary cultigen of the Austronesian peoples. Words for sugarcane are reconstructed as *təbuS or *CebuS in Proto-Austronesian, which became *tebuh in Proto-Malayo-Polynesian. It was one of the original major crops of the Austronesian peoples from at least 5,500 BP. Introduction of the sweeter S. officinarum may have gradually replaced it throughout its cultivated range in maritime Southeast Asia.[14][15][13][16][17]

Map showing sugar cane India as the origin of the westward spread, followed by small areas in Africa, and then smaller areas on Atlantic Islands west of Africa

The westward diffusion of sugarcane in pre-Islamic times (shown in red), in the medieval Muslim world (green), and in the 15th century by the Portuguese on the Madeira archipelago, and by the Spanish on the Canary Islands archipelago (islands west of Africa, circled by violet lines)[18]

From Island Southeast Asia, S. officinarum was spread eastward into Polynesia and Micronesia by Austronesian voyagers as a canoe plant by around 3,500 BP. It was also spread westward and northward by around 3,000 BP to China and India by Austronesian traders, where it further hybridized with S. sinense and S. barberi. From there, it spread further into western Eurasia and the Mediterranean.[12][13]

The earliest known production of crystalline sugar began in northern India. The earliest evidence of sugar production comes from ancient Sanskrit and Pali texts.[19][20][21][22] Around the eighth century, Muslim and Arab traders introduced sugar from medieval India to the other parts of the Abbasid Caliphate in the Mediterranean, Mesopotamia, Egypt, North Africa, and Andalusia. By the 10th century, sources state that every village in Mesopotamia grew sugarcane.[18] It was among the early crops brought to the Americas by the Spanish, mainly Andalusians, from their fields in the Canary Islands, and the Portuguese from their fields in the Madeira Islands. An article on sugarcane cultivation in Spain is included in Ibn al-'Awwam's 12th-century Book on Agriculture.[23]

In colonial times, sugar formed one side of the triangle trade of New World raw materials, along with European manufactured goods, and African slaves. Christopher Columbus first brought sugarcane to the Caribbean (and the New World) during his second voyage to the Americas, initially to the island of Hispaniola (modern day Haiti and the Dominican Republic). The first sugar harvest happened in Hispaniola in 1501; many sugar mills were constructed in Cuba and Jamaica by the 1520s.[24] The Portuguese introduced sugarcane to Brazil. By 1540, there were 800 cane sugar mills in Santa Catarina Island and another 2,000 on the north coast of Brazil, Demarara, and Suriname.[citation needed]

Sugar, often in the form of molasses, was shipped from the Caribbean to Europe or New England, where it was used to make rum. The profits from the sale of sugar were then used to purchase manufactured goods, which were then shipped to West Africa, where they were bartered for slaves. The slaves were then brought back to the Caribbean to be sold to sugar planters. The profits from the sale of the slaves were then used to buy more sugar, which was shipped to Europe. Toil in the sugar plantations became a main basis for a vast network of forced population movement, supplying people to work under brutal coercion.

Lithograph of a sugar plantation in the British colony of Antigua, 1823

Black-and-white photograph of sugarcane standing in field

A sugar plantation on the island of Jamaica in the late 19th century

The passage of the 1833 Slavery Abolition Act led to the abolition of slavery through most of the British Empire, and many of the emancipated slaves no longer worked on sugarcane plantations when they had a choice. West Indian planters, therefore, needed new workers, and they found cheap labour in China and India.[25][26] The people were subject to indenture, a long-established form of contract, which bound them to unfree labour for a fixed term. The conditions where the indentured servants worked were frequently abysmal, owing to a lack of care among the planters.[27] The first ships carrying indentured labourers from India left in 1836.[28] The migrations to serve sugarcane plantations led to a significant number of ethnic Indians, Southeast Asians, and Chinese people settling in various parts of the world.[29] In some islands and countries, the South Asian migrants now constitute between 10 and 50% of the population. Sugarcane plantations and Asian ethnic groups continue to thrive in countries such as Fiji, South Africa, Myanmar, Sri Lanka, Malaysia, Indonesia, the Philippines, Guyana, Jamaica, Trinidad, Martinique, French Guiana, Guadeloupe, Grenada, St. Lucia, St. Vincent, St. Kitts, St. Croix, Suriname, Nevis, and Mauritius.[28][30]

Old-fashioned Indian sugarcane press, circa 1905

Between 1863 and 1900, merchants and plantation owners in Queensland and New South Wales (now part of the Commonwealth of Australia) brought between 55,000 and 62,500 people from the South Pacific Islands to work on sugarcane plantations. An estimated one-third of these workers were coerced or kidnapped into slavery (known as blackbirding). Many others were paid very low wages. Between 1904 and 1908, most of the 10,000 remaining workers were deported in an effort to keep Australia racially homogeneous and protect white workers from cheap foreign labour.[31]

Cuban sugar derived from sugarcane was exported to the USSR, where it received price supports and was ensured a guaranteed market. The 1991 dissolution of the Soviet state forced the closure of most of Cuba's sugar industry.

Sugarcane remains an important part of the economy of Cuba, Guyana, Belize, Barbados, and Haiti, along with the Dominican Republic, Guadeloupe, Jamaica, and other islands.

About 70% of the sugar produced globally comes from S. officinarum and hybrids using this species.[5]

A 19th-century lithograph by Theodore Bray showing a sugarcane plantation: On the right is the "white officer", the European overseer. Slave workers toil during the harvest. To the left is a flat-bottomed vessel for cane transportation.

Cultivation

Sugarcane plantation, Mauritius

Sugarcane plantation in Bangladesh

Planting sugarcane in Puerto Rico

Sugarcane fields

Sugarcane cultivation requires a tropical or subtropical climate, with a minimum of 60 cm (24 in) of annual moisture. It is one of the most efficient photosynthesizers in the plant kingdom. It is a C4 plant, able to convert up to 1% of incident solar energy into biomass.[32] In primary growing regions across the tropics and subtropics, sugarcane crops can produce over 15 kg/m2 of cane.

Sugar cane accounted for around 21% of the global crop production over the 2000–2021 period. The Americas was the leading region in the production of sugar cane (52% of the world total).[33]

Once a major crop of the southeastern region of the United States, sugarcane cultivation declined there during the late 20th century, and is primarily confined to small plantations in Florida, Louisiana, and southeast Texas in the 21st century. Sugarcane cultivation ceased in Hawaii when the last operating sugar plantation in the state shut down in 2016.[34]

Sugarcane is cultivated in the tropics and subtropics in areas with a plentiful supply of water for a continuous period of more than 6–7 months each year, either from natural rainfall or through irrigation. The crop does not tolerate severe frosts. Therefore, most of the world's sugarcane is grown between 22°N and 22°S, and some up to 33°N and 33°S.[35] When sugarcane crops are found outside this range, such as the Natal region of South Africa, it is normally due to anomalous climatic conditions in the region, such as warm ocean currents that sweep down the coast. In terms of altitude, sugarcane crops are found up to 1,600 m or 5,200 ft close to the equator in countries such as Colombia, Ecuador, and Peru.[36]

Sugarcane can be grown on many soils ranging from highly fertile, well-drained mollisols, through heavy cracking vertisols, infertile acid oxisols and ultisols, peaty histosols, to rocky andisols. Both plentiful sunshine and water supplies increase cane production. This has made desert countries with good irrigation facilities such as Egypt some of the highest-yielding sugarcane-cultivating regions. Sugarcane consumes 9% of the world's potash fertilizer production.[37]

Although some sugarcanes produce seeds, modern stem cutting has become the most common reproduction method.[38] Each cutting must contain at least one bud, and the cuttings are sometimes hand-planted. In more technologically advanced countries, such as the United States and Australia, billet planting is common. Billets (stalks or stalk sections) harvested by a mechanical harvester are planted by a machine that opens and recloses the ground. Once planted, a stand can be harvested several times; after each harvest, the cane sends up new stalks, called ratoons.[39] Successive harvests give decreasing yields, eventually justifying replanting. Two to 10 harvests are usually made depending on the type of culture. In a country with a mechanical agriculture looking for a high production of large fields, as in North America, sugarcanes are replanted after two or three harvests to avoid a lowering yields. In countries with a more traditional type of agriculture with smaller fields and hand harvesting, as in the French island of Réunion, sugarcane is often harvested up to 10 years before replanting.[citation needed]

Sugarcane is harvested by hand and mechanically. Hand harvesting accounts for more than half of production, and is dominant in the developing world. In hand harvesting, the field is first set on fire. The fire burns up dry leaves, and chases away or kills venomous snakes, without harming the stalks and roots. Harvesters then cut the cane just above ground-level using cane knives or machetes. A skilled harvester can cut 500 kg (1,100 lb) of sugarcane per hour.[failed verification][40]

Mechanical harvesting uses a combine, or sugarcane harvester.[41] The Austoft 7000 series, the original modern harvester design, has now been copied by other companies, including Cameco / John Deere.[citation needed] The machine cuts the cane at the base of the stalk, strips the leaves, chops the cane into consistent lengths and deposits it into a transporter following alongside. The harvester then blows the trash back onto the field. Such machines can harvest 100 long tons (100 t) each hour, but harvested cane must be rapidly processed. Once cut, sugarcane begins to lose its sugar content, and damage to the cane during mechanical harvesting accelerates this decline. This decline is offset because a modern chopper harvester can complete the harvest faster and more efficiently than hand cutting and loading. Austoft also developed a series of hydraulic high-lift infield transporters to work alongside its harvesters to allow even more rapid transfer of cane to, for example, the nearest railway siding. This mechanical harvesting does not require the field to be set on fire; the residue left in the field by the machine consists of cane tops and dead leaves, which serve as mulch for the next planting.

Plantations in Brazil, the largest producer in the world

Pests

The cane beetle (also known as cane grub) can substantially reduce crop yield by eating roots; it can be controlled with imidacloprid (Confidor) or chlorpyrifos (Lorsban). Other important pests are the larvae of some butterfly/moth species, including the turnip moth, the sugarcane borer (Diatraea saccharalis), the African sugarcane borer (Eldana saccharina), the Mexican rice borer (Eoreuma loftini), the African armyworm (Spodoptera exempta), leafcutter ants, termites, spittlebugs (especially Mahanarva fimbriolata and Deois flavopicta), and Migdolus fryanus (a beetle). The planthopper insect Eumetopina flavipes acts as a virus vector, which causes the sugarcane disease ramu stunt.[42][43] Sesamia grisescens is a major pest in Papua New Guinea and so is a serious concern for the Australian industry were it to cross over.[44] To head off such a problem, the Federal Government has pre-announced that they would cover 80% of response costs if it were necessary.[44]

Pathogens

Main article: List of sugarcane diseases

Numerous pathogens infect sugarcane, such as sugarcane grassy shoot disease caused by Candidatus Phytoplasma sacchari,[45] whiptail disease or sugarcane smut, pokkah boeng caused by Fusarium moniliforme, Xanthomonas axonopodis bacteria causes Gumming Disease, and red rot disease caused by Colletotrichum falcatum. Viral diseases affecting sugarcane include sugarcane mosaic virus, maize streak virus, and sugarcane yellow leaf virus.[46]

Yang et al., 2017 provides a genetic map developed for USDA ARS-run breeding programs for brown rust of sugarcane.[47]

Nitrogen fixation

Some sugarcane varieties are capable of fixing atmospheric nitrogen in association with the bacterium Gluconacetobacter diazotrophicus.[48] Unlike legumes and other nitrogen-fixing plants that form root nodules in the soil in association with bacteria, G. diazotrophicus lives within the intercellular spaces of the sugarcane's stem.[49][50] Coating seeds with the bacteria was assayed in 2006 with the intention of enabling crop species to fix nitrogen for its own use.[51]

Conditions for sugarcane workers

At least 20,000 people are estimated to have died of chronic kidney disease in Central America in the past two decades – most of them sugarcane workers along the Pacific coast. This may be due to working long hours in the heat without adequate fluid intake.[52] Additionally, some of the workers are being exposed to hazards such as: high temperatures, harmful pesticides, and poisonous or venomous animals. This occurs during the process of cutting the sugarcane manually, causing physical ailments due to constant repetitive movements for hours every work day.[53]

Processing

Duration: 1 minute and 59 seconds.1:59

Non-centrifugal cane sugar (jaggery) production near Inle Lake (Myanmar), crushing and boiling stage

Traditionally, sugarcane processing requires two stages. Mills extract raw sugar from freshly harvested cane and "mill-white" sugar is sometimes produced immediately after the first stage at sugar-extraction mills, intended for local consumption. Sugar crystals appear naturally white in color during the crystallization process. Sulfur dioxide is added to inhibit the formation of color-inducing molecules and to stabilize the sugar juices during evaporation.[54][55] Refineries, often located nearer to consumers in North America, Europe, and Japan, then produce refined white sugar, which is 99% sucrose. These two stages are slowly merging. Increasing affluence in the sugarcane-producing tropics increases demand for refined sugar products, driving a trend toward combined milling and refining.[56]

Milling

Main article: Sugar cane mill

Photo of man holding bar that penetrates large tank

Manually extracting juice from sugarcane

Photo of truck hauling trailer

A truck hauls cane to a sugar mill in Florida.

Sugarcane processing produces cane sugar (sucrose) from sugarcane. Other products of the processing include bagasse, molasses, and filtercake.

Bagasse, the residual dry fiber of the cane after cane juice has been extracted, is used for several purposes:[57]

fuel for the boilers and kilns production of paper, paperboard products,

and reconstituted panelboard agricultural mulch as a raw material for

production of chemicals

Photo of shorter building with smoke coming out of smokestack next to five-story office building

Santa Elisa sugarcane processing plant in Sertãozinho, one of the largest and oldest in Brazil

The primary use of bagasse and bagasse residue is as a fuel source for the boilers in the generation of process steam in sugar plants. Dried filtercake is used as an animal feed supplement, fertilizer, and source of sugarcane wax.[citation needed]

Molasses is produced in two forms: blackstrap, which has a characteristic strong flavor, and a purer molasses syrup. Blackstrap molasses is sold as a food and dietary supplement. It is also a common ingredient in animal feed, and is used to produce ethanol, rum, and citric acid. Purer molasses syrups are sold as molasses, and may also be blended with maple syrup, invert sugars, or corn syrup. Both forms of molasses are used in baking.[citation needed]

Refining

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Brown and white sugar crystals

Sugar refining further purifies the raw sugar. It is first mixed with heavy syrup and then centrifuged in a process called "affination". Its purpose is to wash away the sugar crystals' outer coating, which is less pure than the crystal interior. The remaining sugar is then dissolved to make a syrup, about 60% solids by weight.

The sugar solution is clarified by the addition of phosphoric acid and calcium hydroxide, which combine to precipitate calcium phosphate. The calcium phosphate particles entrap some impurities and absorb others, and then float to the top of the tank, where they can be skimmed off. An alternative to this "phosphatation" technique is "carbonatation", which is similar, but uses carbon dioxide and calcium hydroxide to produce a calcium carbonate precipitate.

After filtering any remaining solids, the clarified syrup is decolorized by filtration through activated carbon. Bone char or coal-based activated carbon is traditionally used in this role.[58] Some remaining color-forming impurities are adsorbed by the carbon. The purified syrup is then concentrated to supersaturation and repeatedly crystallized in a vacuum, to produce white refined sugar. As in a sugar mill, the sugar crystals are separated from the molasses by centrifuging. Additional sugar is recovered by blending the remaining syrup with the washings from affination and again crystallizing to produce brown sugar. When no more sugar can be economically recovered, the final molasses still contains 20–30% sucrose and 15–25% glucose and fructose.

To produce granulated sugar, in which individual grains do not clump, sugar must be dried, first by heating in a rotary dryer, and then by blowing cool air through it for several days.

Ribbon cane syrup

Ribbon cane is a subtropical type that was once widely grown in the Southern United States, as far north as coastal North Carolina. The juice was extracted with horse- or mule-powered crushers; the juice was boiled, like maple syrup, in a flat pan, and then used in the syrup form as a food sweetener.[59] It is not currently a commercial crop, but a few growers find ready sales for their product.[citation needed]

Production of sugarcane (2019)[60]

Production

Top Sugarcane producers in

2020

Numbers in million tonnes

1. Brazil 757.1 (40.49%)
2. India 370.5 (19.82%)
3. China 108.1 (5.78%)
4. Pakistan 81 (4.33%)
5. Thailand 75 (4.01%)
6. Mexico 54 (2.89%)
7. United States 32.7 (1.75%)
8. Australia 30 (1.6%) World total 1,869.7

Source: FAOSTAT[61]

In 2020, global production of sugarcane was 1.87 billion tonnes, with Brazil producing 40% of the world total, India with 20%, and China producing 6% (table).

Worldwide, 26 million hectares were devoted to sugarcane cultivation in 2020.[61] The average worldwide yield of sugarcane crops in 2020 was 71 tonnes per hectare, led by Peru with 123 tonnes per hectare.[61] The theoretical possible yield for sugarcane is about 280 tonnes per hectare per year, and small experimental plots in Brazil have demonstrated yields of 236–280 tonnes of cane per hectare.[62][63]

From 2008 to 2016, production of standards-compliant sugarcane experienced a compound annual growth rate of about 52%, while conventional sugarcane increased at less than 1%.[64]

Environmental impacts

Soil degradation and erosion

The cultivation of sugarcane can lead to increased soil loss through the removal of soil at harvest, as well as improper irrigation practices, which can result in erosion.[65][66] Erosion is especially significant when the sugarcane is grown on slopes or hillsides, which increases the rate of water runoff.[65][66] Generally, it is recommended that sugarcane is not planted in areas with a slope greater than 8%.[65] However, in certain areas, such as parts of the Caribbean and South Africa, slopes greater than 20% have been planted.[65] Increased erosion can lead to the removal of organic and nutrient-rich material, which can decrease future crop yields. It can also result in sediments and other pollutants being washed into aquatic habitats, which can result in a wide range of environmental issues, including eutrophication and acidification.[65][66]

Sugarcane cultivation can also result in soil compaction, which is caused by the use of heavy, infield machinery.[65] Along with impacting invertebrate and fauna within the upper layers of the soil, compaction can also lead to decreased porosity.[65][66] This in turn can increase surface runoff, resulting in greater leaching and erosion.[65]

Habitat destruction

Gases produced from sugarcane processing.

Due to the large quantity of water required, sugarcane cultivation heavily relies on irrigation.[67] Additionally, since large amounts of soil are removed with the crop during harvest, significant washing occurs during the processing phase.[67] In many countries, such as India and Australia, this requirement has placed a strain on available resources, requiring the construction of barrages and other dams.[65][67] This has altered the amount of water reaching aquatic habitats, and has contributed to the degradation of ecosystems such as the Great Barrier Reef and Indus Delta.[65][67]

Land cleared for sugarcane production.

Sugarcane has also contributed to habitat destruction through the clearance of land.[65] Seven countries around the world devote more than 50% of their land to the cultivation of sugarcane.[65] Sugarcane fields have replaced tropical rain forests and wetlands.[65] While the majority of this clearance occurred in the past, expansions have occurred within the past couple decades, further contributing to habitat destruction.[66]

Mitigation efforts

A wide variety of mitigation efforts can be implemented to reduce the impacts of sugarcane cultivation.[65] Among these efforts is switching to alternative irrigation techniques, such as drip irrigation, which are more water efficient.[65] Water efficiency can also be improved by employing methods such as trash mulching, which has been shown to increase water intake and storage.[65][68] Along with reducing the overall water use, this method can also decrease soil runoff, and therefore prevent pollutants from entering the environment.[65] In areas with a slope greater than 11%, it is also recommended that zero tillage or cane strip planting are implemented to help prevent soil loss.[65]

Sugarcane processing produces a wide variety of pollutants, including heavy metals and bagasse, which can be released into the environment through wastewater discharge.[65] To prevent this, alternative treatment methods such as high rate anaerobic digestions can be implemented to better treat this wastewater.[69] Stormwater drains can also be installed to prevent uncontrolled runoff from reaching aquatic ecosystems.[65]

Ethanol

Further information: Ethanol fuel

See also: Biofuel

A fuel pump in Brazil, offering cane ethanol (A) and gasoline (G)

Ethanol is generally available as a byproduct of sugar production. It can be used as a biofuel alternative to gasoline, and is widely used in cars in Brazil. It is an alternative to gasoline, and may become the primary product of sugarcane processing, rather than sugar[citation needed]

In Brazil, gasoline is required to contain at least 22% bioethanol.[70] This bioethanol is sourced from Brazil's large sugarcane crop.

The production of ethanol from sugarcane is more energy efficient than from corn or sugar beets or palm/vegetable oils, particularly if cane bagasse is used to produce heat and power for the process. Furthermore, if biofuels are used for crop production and transport, the fossil energy input needed for each ethanol energy unit can be very low. EIA estimates that with an integrated sugarcane to ethanol technology, the well-to-wheels CO2 emissions can be 90% lower than conventional gasoline.[70] A textbook on renewable energy[71] describes the energy transformation:

Presently, 75 tons of raw sugarcane are produced annually per hectare in Brazil. The cane delivered to the processing plant is called burned and cropped (b&c), and represents 77% of the mass of the raw cane. The reason for this reduction is that the stalks are separated from the leaves (which are burned and whose ashes are left in the field as fertilizer), and from the roots that remain in the ground to sprout for the next crop. Average cane production is, therefore, 58 tons of b&c per hectare per year.

Each ton of b&c yields 740 kg of juice (135 kg of sucrose and 605 kg of water) and 260 kg of moist bagasse (130 kg of dry bagasse). Since the lower heating value of sucrose is 16.5 MJ/kg, and that of the bagasse is 19.2 MJ/kg, the total heating value of a ton of b&c is 4.7 GJ of which 2.2 GJ come from the sucrose and 2.5 from the bagasse.

Per hectare per year, the biomass produced corresponds to 0.27 TJ. This is equivalent to 0.86 W per square meter. Assuming an average insolation of 225 W per square meter, the photosynthetic efficiency of sugar cane is 0.38%.

The 135 kg of sucrose found in 1 ton of b&c are transformed into 70 litres of ethanol with a combustion energy of 1.7 GJ. The practical sucrose-ethanol conversion efficiency is, therefore, 76% (compare with the theoretical 97%).

One hectare of sugar cane yields 4,000 litres of ethanol per year (without any additional energy input, because the bagasse produced exceeds the amount needed to distill the final product). This, however, does not include the energy used in tilling, transportation, and so on. Thus, the solar energy-to-ethanol conversion efficiency is 0.13%.

Bagasse applications

Sugarcane bagasse

Sugarcane is a major crop in many countries. It is one of the plants with the highest bioconversion efficiency. Sugarcane crop is able to efficiently fix solar energy, yielding some 55 tonnes of dry matter per hectare of land annually. After harvest, the crop produces sugar juice and bagasse, the fibrous dry matter. This dry matter is biomass with potential as fuel for energy production. Bagasse can also be used as an alternative source of pulp for paper production.[72]

Sugarcane bagasse is a potentially abundant source of energy for large producers of sugarcane, such as Brazil, India, and China. According to one report, with use of latest technologies, bagasse produced annually in Brazil has the potential of meeting 20% of Brazil's energy consumption by 2020.[73]

Electricity production

A number of countries, in particular those lacking fossil fuels, have implemented energy conservation and efficiency measures to minimize the energy used in cane processing, and export any excess electricity to the grid. Bagasse is usually burned to produce steam, which in turn creates electricity. Current technologies, such as those in use in Mauritius, produce over 100 kWh of electricity per tonne of bagasse. With a total world harvest of over one billion tonnes of sugarcane per year, the global energy potential from bagasse is over 100,000 GWh.[74] Using Mauritius as a reference, an annual potential of 10,000 GWh of additional electricity could be produced throughout Africa.[75] Electrical generation from bagasse could become quite important, particularly to the rural populations of sugarcane producing nations.

Recent cogeneration technology plants are being designed to produce from 200 to over 300 kWh of electricity per tonne of bagasse.[76][77] As sugarcane is a seasonal crop, shortly after harvest the supply of bagasse would peak, requiring power generation plants to strategically manage the storage of bagasse.

Biogas production

A greener alternative to burning bagasse for the production of electricity is to convert bagasse into biogas. Technologies are being developed to use enzymes to transform bagasse into advanced biofuel and biogas.[73]

Sugarcane as food

Further information: Sugar

Cane juice[78]

Freshly squeezed sugarcane juice

Nutritional value per 100 grams

Energy 242 kJ (58 kcal)

Carbohydrates

13.11 g

Sugars 12.85 g

Dietary fiber 0.56 g

Fat

0.40

Protein

0.16 g

Vitamins	Quantity%DV†
Vitamin B6	24%0.40 mg
Folate (B9)	11%44.53 μg
Vitamin C	7%6.73 mg
Minerals	Quantity%DV†

Calcium 1%18 mg

Iron	6%1.12 mg
Magnesium	3%13.03 mg
Phosphorus	2%22.08 mg
Potassium	5%150 mg
Sodium	0%1.16 mg
Zinc	1%0.14 mg

Nutrient Information from Indian Food Composition Database

†Percentages estimated using US recommendations for adults.[79]

In most countries where sugarcane is cultivated, several foods and popular dishes are derived directly from it, such as:

Raw sugarcane: chewed to extract the juice

Sayur nganten: an Indonesian soup made with the stem of trubuk (Saccharum edule), a type of sugarcane

Sugarcane juice: a combination of fresh juice, extracted by hand or small mills, with a touch of lemon and ice to make a popular drink, known variously as air tebu, usacha rass, guarab, guarapa, guarapo, papelón, aseer asab, ganna sharbat, mosto, caldo de cana, or nước mía

Syrup: a traditional sweetener in soft drinks worldwide but now largely supplanted in the US by high fructose corn syrup, which is less expensive because of corn subsidies and sugar tariffs[80]

Molasses: used as a sweetener and a syrup accompanying other foods, such as cheese or cookies

Jaggery: a solidified molasses, known as gur, gud, or gul in South Asia, is traditionally produced by evaporating juice to make a thick sludge, and then cooling and molding it in buckets. Modern production partially freeze dries the juice to reduce caramelization and lighten its color. It is used as sweetener in cooking traditional entrees, sweets, and desserts.

Falernum: a sweet, and slightly alcoholic drink made from sugarcane juice

Cachaça: the most popular distilled alcoholic beverage in Brazil; it is a liquor made of the distillation of sugarcane juice.

Rum is a liquor made from sugarcane products, typically molasses, but sometimes also cane juice. It is most commonly produced in the Caribbean and environs.

Basi is a fermented alcoholic beverage made from sugarcane juice produced in the Philippines and Guyana.

Panela, solid pieces of sucrose and fructose obtained from the boiling and evaporation of sugarcane juice, is a food staple in Colombia and other countries in South and Central America.

Rapadura is a sweet flour that is one of the simplest refinings of sugarcane juice, common in Latin American countries such as Brazil, Argentina, and Venezuela (where it is known as papelón) and the Caribbean.

Rock candy: crystallized cane juice

Gâteau de Sirop

Viche, a homebrewed Colombian alcoholic beverage

Sugarcane as feed

Many parts of the sugarcane are commonly used as animal feeds where the plants are cultivated. The leaves make a good forage for ruminants.

Flax

Tools

From Wikipedia, the free encyclopedia

For other uses, see Flax (disambiguation).

Flax

Scientific classificationEdit this classification

Kingdom: Plantae

Clade: Tracheophytes

Clade: Angiosperms

Clade: Eudicots

Clade: Rosids

Order: Malpighiales

Family: Linaceae

Genus: Linum

Species: L. usitatissimum

Binomial name Linum

usitatissimum

L.

Synonyms[1]

Linum crepitans (Boenn.) Dumort.

Linum humile Mill.

Linum indehiscens (Neilr.) Vavilov & Elladi

Flax, also known as common flax or linseed, is a flowering plant, Linum usitatissimum, in the family Linaceae. It is cultivated as a food and fiber crop in regions of the world with temperate climates. Textiles made from flax are known in English as linen and are traditionally used for bed sheets, underclothes, and table linen. Its oil is known as linseed oil. In addition to referring to the plant, the word "flax" may refer to the unspun fibers of the flax plant. The plant species is known only as a cultivated plant[2] and appears to have been domesticated just once from the wild species Linum bienne, called pale flax.[3] The plants called "flax" in New Zealand are, by contrast, members of the genus Phormium.

Description

Capsules

Flowers

Light-coloured flower

Several other species in the genus Linum are similar in appearance to L. usitatissimum, cultivated flax, including some that have similar blue flowers, and others with white, yellow, or red flowers.[4] Some of these are perennial plants, unlike L. usitatissimum, which is an annual plant.

Cultivated flax plants grow to 1.2 m (3 ft 11 in) tall, with slender stems. The leaves are glaucous green, slender lanceolate, 20–40 mm long, and 3 mm broad.[5]

The flowers are 15–25 mm in diameter with five petals, which can be colored white, blue, yellow, and red depending on the species.[5] The fruit is a round, dry capsule 5–9 mm in diameter, containing several glossy brown seeds shaped like apple pips, 4–7 mm long.

History

The earliest evidence of humans using wild flax as a textile comes from the present-day Republic of Georgia, where spun, dyed, and knotted wild flax fibers found in Dzudzuana Cave date to the Upper Paleolithic, 30,000 years ago.[6][7][8] Humans first domesticated flax in the Fertile Crescent region.[9] Evidence exists of a domesticated oilseed flax with increased seed-size from Tell Ramad in Syria[9] and flax fabric fragments from Çatalhöyük in Turkey[10] by c. 9,000 years ago. Use of the crop steadily spread, reaching as far as Switzerland and Germany by 5,000 years ago.[11] In China and India, domesticated flax was cultivated at least 5,000 years ago.[12]

Flax was cultivated extensively in ancient Egypt, where the temple walls had paintings of flowering flax, and mummies were embalmed using linen.[13] Egyptian priests wore only linen, as flax was considered a symbol of purity.[14] Phoenicians traded Egyptian linen throughout the Mediterranean and the Romans used it for their sails.[15] As the Roman Empire declined, so did flax production. But with laws designed to publicize the hygiene of linen textiles and the health of linseed oil, Charlemagne revived the crop in the eighth century CE.[16] Eventually, Flanders became the major center of the European linen industry in the Middle Ages.[16] In North America, colonists introduced flax, and it flourished there,[12] but by the early 20th century, cheap cotton and rising farm wages had caused production of flax to become concentrated in northern Russia, which came to provide 90% of the world's output. Since then, flax has lost its importance as a commercial crop, due to the easy availability of more durable fibres.[17]

Uses

Brown flax seeds

Golden flax seeds

Golden flax seed meal

Flax is grown for its seeds, which can be ground into a meal or turned into linseed oil, a product used as a nutritional supplement and as an ingredient in many wood-finishing products. Flax is also grown as an ornamental plant in gardens. Moreover, flax fibers are used to make linen. The specific epithet in its binomial name, usitatissimum, means "most useful".[18]

Flax fibers taken from the stem of the plant are two to three times as strong as cotton fibers. Additionally, flax fibers are naturally smooth and straight. Europe and North America both depended on flax for plant-based cloth until the 19th century, when cotton overtook flax as the most common plant for making rag-based paper. Flax is grown on the Canadian prairies for linseed oil, which is used as a drying oil in paints and varnishes and in products such as linoleum and printing inks.

Linseed meal, the by-product of producing linseed oil from flax seeds, is used as livestock fodder.[19]

Flax seeds

Flax seeds occur in brown and yellow (golden) varieties.[20] Most types of these basic varieties have similar nutritional characteristics and equal numbers of short-chain omega-3 fatty acids. Yellow flax seeds, called solin (trade name "Linola"),[21] have a similar oil profile to brown flax seeds and both are very high in omega-3s (alpha-linolenic acid (ALA), specifically).[22] Flax seeds produce a vegetable oil known as flax seed oil or linseed oil, which is one of the oldest commercial oils. It is an edible oil obtained by expeller pressing and sometimes followed by solvent extraction. Solvent-processed flax seed oil has been used for many centuries as a drying oil in painting and varnishing.[23]

Although brown flax seed varieties may be consumed as readily as the yellow ones, and have been for thousands of years, these varieties are more commonly used in paints, for fiber, and for cattle feed.

Culinary

Small pieces of dough being topped with flax seeds before baking in a commercial bakery

Bread rolls being topped with flax seeds before baking

A 100-gram portion of ground flax seed supplies about 2,234 kilojoules (534 kilocalories) of food energy, 41 g of fat, 28 g of fiber, and 20 g of protein.[24] Whole flax seeds are chemically stable, but ground flax seed meal, because of oxidation, may go rancid when left exposed to air at room temperature in as little as a week.[25] Refrigeration and storage in sealed containers will keep ground flax seed meal for a longer period before it turns rancid. Under conditions similar to those found in commercial bakeries, trained sensory panelists could not detect differences between bread made with freshly ground flax seed and bread made with flax seed that had been milled four months earlier and stored at room temperature.[26] If packed immediately without exposure to air and light, milled flax seed is stable against excessive oxidation when stored for nine months at room temperature,[27] and under warehouse conditions, for 20 months at ambient temperatures.[citation needed]

Three phenolic glucosides—secoisolariciresinol diglucoside, p-coumaric acid glucoside, and ferulic acid glucoside—are present in commercial breads containing flax seed.[28]

Fodder

After crushing the seeds to extract linseed oil, the resultant linseed meal is a protein-rich feed for ruminants, rabbits, and fish.[19] It is also often used as feed for swine and poultry, and has also been used in horse concentrate and dog food.[29] The high omega-3 fatty acid (ALA) content of linseed meal "softens" milk, eggs, and meat, which means it causes a higher unsaturated fat content and thus lowers its storage time.[19] The high omega-3 content also has a further disadvantage, because this fatty acid oxidises and goes rancid quickly, which shortens the storage time. Linola was developed in Australia and introduced in the 1990s with less omega-3, specifically to serve as fodder.[21][30] Another disadvantage of the meal and seed is that it contains a vitamin B6 (pyridoxine) antagonist, and may require this vitamin be supplemented, especially in chickens, and furthermore linseeds contain 2–7% of mucilage (fibre), which may be beneficial in humans[19] and cattle,[29] but cannot be digested by non-ruminants and can be detrimental to young animals, unless possibly treated with enzymes.[19]

Linseed meal is added to cattle feed as a protein supplement. It can only be added at low percentages due to the high fat content, which is unhealthy for ruminants.[29] Compared to oilseed meal from crucifers it measures as having lower nutrient values,[19] however, good results are obtained in cattle, perhaps due to the mucilage, which may aid in slowing digestion and thus allowing more time to absorb nutrients.[19][29] One study found that feeding flax seeds may increase omega-3 content in beef, while another found no differences. It might also act as a substitute for tallow in increasing marbling.[29][31] In the US, flax-based feed for ruminants is often somewhat more expensive than other feeds on a nutrient basis.[32] Sheep feeding on low quality forage are able to eat a large amount of linseed meal, up to 40% in one test, with positive consequences. It has been fed as supplement to water buffaloes in India, and provided a better diet than forage alone, but not as good as when substituted with soy meal.

It is considered an inferior protein supplement for swine because of its fibre, the vitamin antagonist, the high omega-3 content and its low lysine content, and can only be used in small amounts in the feed. Although it may increase the omega-3 content in eggs and meat, it is also an inferior and potentially toxic feed for poultry, although it can be used in small amounts. The meal is an adequate and traditional source of protein for rabbits at 8–10%. Its use in fish feeds is limited.[19]

Raw, immature linseeds contain an amount of cyanogenic compounds and can be dangerous for monogastric animals, like horses and rabbits. Boiling removes the danger. This is not an issue in meal cake due to the processing temperature during oil extraction.[19][32]

Flax straw left over from the harvesting of oilseed is not very nutritious; it is tough and indigestible, and is not recommended to use as ruminant fodder, although it may be used as bedding or baled as windbreaks.[32]

Flax fibers

An 18th century heckling shop once used to prepare flax fibers. North Ayrshire, Scotland.

Flax fiber is extracted from the bast beneath the surface of the stem of the flax plant. Flax fiber is soft, lustrous, and flexible; bundles of fiber have the appearance of blonde hair, hence the description "flaxen" hair. It is stronger than cotton fiber, but less elastic.

A flax field in bloom in North Dakota

The use of flax fibers dates back tens of millennia;[6] linen, a refined textile made from flax fibers, was worn widely by Sumerian priests more than 4,000 years ago.[33] Industrial-scale flax fiber processing existed in antiquity. A Bronze Age factory dedicated to flax processing was discovered in Euonymeia, Greece.[34]

The best grades are used for fabrics such as damasks, lace, and sheeting. Coarser grades are used for the manufacturing of twine and rope, and historically, for canvas and webbing equipment. Flax fiber is a raw material used in the high-quality paper industry for the use of printed banknotes, laboratory paper (blotting and filter), rolling paper for cigarettes, and tea bags.[35]

Flax mills for spinning flaxen yarn were invented by John Kendrew and Thomas Porthouse of Darlington, England, in 1787.[36] New methods of processing flax have led to renewed interest in the use of flax as an industrial fiber.

Nutrition

Flax seeds

Nutritional value per 100 g (3.5 oz)

Energy 2,234 kJ (534 kcal)

Carbohydrates

28.88 g

Sugars 1.55 g

Dietary fiber 27.3 g

Fat

42.16 g

Saturated 3.663 g

Monounsaturated 7.527 g

Polyunsaturated

omega-3 omega-6

28.730 g

22.8 g

5.9 g

Protein

18.29 g

Vitamins Quantity%DV†

Thiamine (B1) 137%1.644 mg

Riboflavin (B2) 12%0.161 mg

Niacin (B3) 19%3.08 mg

Pantothenic acid (B5) 20%0.985 mg

Vitamin B6 28%0.473 mg

Folate (B9) 22%87 µg

Vitamin C	1%0.6 mg
Minerals	Quantity%DV†
Calcium	20%255 mg
Iron	32%5.73 mg
Magnesium	93%392 mg
Phosphorus	51%642 mg
Potassium	27%813 mg
Zinc	39%4.34 mg
Other constituents	Quantity
Water	7 g

Link to USDA Database entry

†Percentages estimated using US recommendations for adults.[37]

Flax seeds are 7% water, 18% protein, 29% carbohydrates, and 42% fat (table). In 100 grams (3.5 oz) as a reference amount, flax seeds provide 534 kilocalories and contain high levels (20% or more of the Daily Value, DV) of protein, dietary fiber, several B vitamins, and dietary minerals.[38][39] Flax seeds are especially rich in thiamine, magnesium, and phosphorus (DVs above 90%) (table).

As a percentage of total fat, flax seeds contain 54% omega-3 fatty acids (mostly ALA), 18% omega-9 fatty acids (oleic acid), and 6% omega-6 fatty acids (linoleic acid); the seeds contain 9% saturated fat, including 5% as palmitic acid.[38][39] Flax seed oil contains 53% 18:3 omega-3 fatty acids (mostly ALA) and 13% 18:2 omega-6 fatty acids.[38]

Health research

A meta-analysis showed that consumption of more than 30 g of flax-seed daily for more than 12 weeks reduced body weight, body mass index (BMI), and waist circumference for persons with a BMI greater than 27.[40] Another meta-analysis showed that consumption of flax seeds for more than 12 weeks produced small reductions in systolic blood pressure and diastolic blood pressure.[41] A third showed that consuming flax seed or its derivatives may reduce total and LDL-cholesterol in the blood, with greater benefits in women and people with high cholesterol.[42] A fourth showed a small reduction in creactive protein (a marker of inflammation) only in persons with a body mass index greater than 30.[43]

Linseed oil

This section is an excerpt from Linseed oil.[edit]

Flax, flax seeds, linseed oil, linseed cake

Linseed oil, also known as flaxseed oil or flax oil (in its edible form), is a colourless to yellowish oil obtained from the dried, ripened seeds of the flax plant (Linum usitatissimum). The oil is obtained by pressing, sometimes followed by solvent extraction.

Owing to its polymer-forming properties, linseed oil is often blended with combinations of other oils, resins or solvents as an impregnator, drying oil finish or varnish in wood finishing, as a pigment binder in oil paints, as a plasticizer and hardener in putty, and in the manufacture of linoleum. Linseed oil use has declined over the past several decades with increased availability of synthetic alkyd resins—which function similarly but resist yellowing.[44]

Linseed oil is an edible oil in demand as a dietary supplement, as a source of α-linolenic acid, an omega-3 fatty acid. In parts of Europe, it is traditionally eaten with potatoes and quark.

Safety

Flax seed and its oil are generally recognized as safe for human consumption.[45] Like many common foods, flax contains small amounts of cyanogenic glycoside,[46] which is nontoxic when consumed in typical amounts.[47] Typical concentrations (for example, 0.48% in a sample of defatted dehusked flax seed meal) can be removed by special processing.[48]

Cultivation

The soils most suitable for flax, besides the alluvial kind, are deep loams containing a large proportion of organic matter.[49] Flax is often found growing just above the waterline in cranberry bogs. Heavy clays are unsuitable, as are soils of a gravelly or dry sandy nature. Farming flax requires few fertilizers or pesticides. Within eight weeks of sowing, the plant can reach 10–15 cm (3.9–5.9 in) in height, reaching 70–80 cm (28–31 in) within 50 days.[citation needed]

Diseases

Main article: List of flax diseases

Production

In 2020, world production of flax (linseed) was 3.4 million tonnes, led by Kazakhstan with 31% of the total.[50] Other major producers were Russia, Canada, and China (table).

Flax (linseed) production – 2020

Country	Production (tonnes)
Kazakhstan	1,058,247
Russia	787,923
Canada	578,000
China	330,000
World	3,367,331

Source: FAOSTAT of the United Nations[50]

Harvesting

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Maturation

Flax is harvested for fiber production after about 100 days, or a month after the plants flower and two weeks after the seed capsules form. The bases of the plants begin to turn yellow. If the plants are still green, the seed will not be useful, and the fiber will be underdeveloped. The fiber degrades once the plants turn brown.

Flax grown for seed is allowed to mature until the seed capsules are yellow and just starting to split; it is then harvested in various ways. A combine harvester may either cut only the heads of the plants, or the whole plant. These are then dried to extract the seed. The amount of weeds in the straw affects its marketability, and this, coupled with market prices, determines whether the farmer chooses to harvest the flax straw. If the flax straw is not harvested, typically, it is burned, since the stalks are quite tough and decompose slowly (i.e., not in a single season). Formed into windrows from the harvesting process, the straw often clogs up tillage and planting equipment. Flax straw that is not of sufficient quality for fiber uses can be baled to build shelters for farm animals, or sold as biofuel, or removed from the field in the spring.[51]

Two ways are used to harvest flax fiber, one involving mechanized equipment (combines), and a second method, more manual and targeting maximum fiber length.

Harvesting for fiber

Mechanical

Flax for fiber production is usually harvested by a specialized flax harvester. Usually built on the same machine base as a combine, but instead of the cutting head it has a flax puller. The flax plant is turned over and is gripped by rubber belts roughly 20–25 cm (8–10 inches) above ground, to avoid getting grasses and weeds in the flax. The rubber belts then pull the whole plant out of the ground with the roots so the whole length of the plant fiber can be used. The plants then pass over the machine and is placed on the field crosswise to the harvester's direction of travel. The plants are left in the field for field retting.

The mature plant can also be cut with mowing equipment, similar to hay harvesting, and raked into windrows. When dried sufficiently, a combine then harvests the seeds similar to wheat or oat harvesting.

Manual

The plant is pulled up with the roots (not cut), so as to increase the fiber length. After this, the flax is allowed to dry, the seeds are removed, and it is then retted. Dependent upon climatic conditions, characteristics of the sown flax and fields, the flax remains on the ground between two weeks and two months for retting. As a result of alternating rain and the sun, an enzymatic action degrades the pectins which bind fibers to the straw. The farmers turn over the straw during retting to evenly rett the stalks. When the straw is retted and sufficiently dry, it is rolled up. It is then stored by farmers before extracting the fibers.

De vlasoogst (1904) ("The flax harvest") painting by Emile Claus, Royal Museums of Fine Arts of Belgium, Brussels, Belgium

Processing

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A hackle or heckle, a tool for threshing flax and preparing the fiber

Flax tissues, Tacuinum sanitatis, 14th century

Threshing is the process of removing the seeds from the rest of the plant. Separating the usable flax fibers from other components requires pulling the stems through a hackle and/or beating the plants to break them.

Flax processing is divided into two parts: the first part is generally done by the farmer, to bring the flax fiber into a fit state for general or common purposes. This can be performed by three machines: one for threshing out the seed, one for breaking and separating the straw (stem) from the fiber, and one for further separating the broken straw and matter from the fiber.

The second part of the process brings the flax into a state for the very finest purposes, such as lace, cambric, damask, and very fine linen. This second part is performed by a refining machine.

Preparation for spinning

Stem cross-section, showing locations of underlying tissues: Ep = epidermis; C = cortex; BF = bast fibers; P = phloem; X = xylem; Pi = pith

Duration: 3 minutes and 33 seconds.3:33

Threshing, retting, and dressing flax at the Roscheider Hof Open Air Museum (Germany)

Before the flax fibers can be spun into linen, they must be separated from the rest of the stalk. The first step in this process is retting, which is the process of rotting away the inner stalk, leaving the outer parts intact. At this point, straw, or coarse outer stem (cortex and epidermis), is still remaining. To remove this, the flax is "broken", the straw is broken up into small, short bits, while the actual fiber is left unharmed. Scutching scrapes the outer straw from the fiber. The stems are then pulled through "hackles", which act like combs to remove the straw and some shorter fibers out of the long fiber.[citation needed]

Retting flax

Several methods are used for retting flax. It can be retted in a pond, stream, field, or tank. When the retting is complete, the bundles of flax feel soft and slimy, and quite a few fibers are standing out from the stalks. When wrapped around a finger, the inner woody part springs away from the fibers. Pond retting is the fastest. It consists of placing the flax in a pool of water which will not evaporate. It generally takes place in a shallow pool which will warm up dramatically in the sun; the process may take from a few days to a few weeks. Pond-retted flax is traditionally considered of lower quality, possibly because the product can become dirty, and is easily over-retted, damaging the fiber. This form of retting also produces quite an odor. Stream retting is similar to pool retting, but the flax is submerged in bundles in a stream or river. This generally takes two or three weeks longer than pond retting, but the end product is less likely to be dirty, does not smell as bad, and because the water is cooler, is less likely to be overretted. Both pond and stream retting were traditionally used less because they pollute the waters used for the process.[citation needed]

In field retting, the flax is laid out in a large field, and dew is allowed to collect on it. This process normally takes a month or more, but is generally considered to provide the highest quality flax fibers, and it produces the least pollution.[52]

Retting can also be done in a plastic trash can or any type of water-tight container of wood, concrete, earthenware, or plastic. Metal containers will not work, as an acid is produced when retting, and it would corrode the metal. If the water temperature is kept at 27 °C (80 °F), the retting process under these conditions takes 4 or 5 days. If the water is any colder, it takes longer. Scum collects at the top, and an odor is given off the same as in pond retting. 'Enzymatic' retting of flax has been researched as a technique to engineer fibers with specific properties.[53][54]

Dressing the flax

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Breaking flax Breaking

flax

Scutching flax Scutching

flax

Heckling flax

Heckling flax

Flax fiber in different forms, before and after processing

Flax fiber in different forms, before and after processing

Dressing the flax is the process of removing the straw from the fibers. Dressing consists of three steps: breaking, scutching, and heckling. The breaking breaks up the straw. Some of the straw is scraped from the fibers in the scutching process, and finally, the fiber is pulled through heckles to remove the last bits of straw.

Breaking breaks up the straw into short segments.

Scutching removes some of the straw from the fiber.

Heckling is pulling the fiber through various sizes of heckling combs or heckles. A heckle is a bed of "nails"—sharp, long-tapered, tempered, polished steel pins driven into wooden blocks at regular spacing.

Genetically modified flax contamination

Small flax plants

In September 2009, Canadian flax exports reportedly had been contaminated by a deregistered genetically modified cultivar called 'Triffid' that had food and feed safety approval in Canada and the U.S.[55][56] Canadian growers and the Flax Council of Canada raised concerns about the marketability of this cultivar in Europe where a zero tolerance policy exists regarding unapproved genetically modified organisms.[57] Consequently, Triffid was deregistered in 2010 and never grown commercially in Canada or the U.S.[58] Triffid stores were destroyed, but future exports and further tests at the University of Saskatchewan proved that Triffid persisted in at least two Canadian flax varieties, possibly affecting future crops.[58] Canadian flax seed cultivars were reconstituted with Triffid-free seed used to plant the 2014 crop.[55] Laboratories are certified to test for the presence of Triffid at a level of one seed in 10,000.[56]

Symbolic images

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Four flax flowers pictured in the coat of arms of Mulgi Parish

Flax is an emblem of Northern Ireland and displayed by the Northern Ireland Assembly. In a coronet, it appeared on the reverse of the British one-pound coin to represent Northern Ireland on coins minted in 1986, 1991, and 2014. Flax also represents Northern Ireland on the badge of the Supreme Court of the United Kingdom and on various logos associated with it.

Common flax is the national flower of Belarus.

In early versions of the Sleeping Beauty tale, such as "Sun, Moon, and Talia" by Giambattista Basile, the princess pricks her finger, not on a spindle, but on a sliver of flax, which later is sucked out by her children conceived as she sleeps.

Mustard (condiment)

Article

Talk

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Tools

From Wikipedia, the free encyclopedia

Mustard

Prepared mustard in a bowl

Course Condiment

Region or state Worldwide distribution

Main ingredients Mustard seed, water, vinegar, salt

Media: Mustard

Mustard seeds (top left) may be ground (top right) to make different kinds of mustard. These four mustards are: English mustard with turmeric coloring (center left), a Bavarian sweet mustard (center right), a Dijon mustard (lower left), and a coarse French mustard made mainly from black mustard seeds (lower right).

Mustard is a condiment made from the seeds of a mustard plant (white/yellow mustard, Sinapis alba; brown mustard, Brassica juncea; or black mustard, Brassica nigra).

The whole, ground, cracked, or bruised mustard seeds are mixed with water, vinegar, lemon juice, wine, or other liquids, salt, and often other flavorings and spices, to create a paste or sauce ranging in color from bright yellow to dark brown. The seed itself has a strong, pungent, and somewhat bitter taste. The taste of mustard condiments ranges from sweet to spicy.

Mustard is commonly paired with meats, vegetables and cheeses, especially as a condiment for sandwiches, hamburgers, and hot dogs. It is also used as an ingredient in many dressings, glazes, sauces, soups, and marinades. As a paste or as individual seeds, mustard is used as a condiment in the cuisine of India and Bangladesh, the Mediterranean, northern and southeastern Europe, Asia, the Americas, and Africa,[1] making it one of the most popular and widely used spices and condiments in the world.[2]

Etymology

The English word "mustard" derives from the Anglo-Norman mustarde and Old French mostarde. (Modern French is moutarde.) The first element is ultimately from Latin mustum ("must", unfermented grape juice)—the condiment was originally prepared by making the ground seeds into a paste with must or verjuice. It was first attested in English in the late 13th century, though it was found as a surname a century earlier.[3]

History

Archaeological excavations in the Indus Valley (Indian Subcontinent) have revealed that mustard was cultivated there. That civilization existed until about 1850 BCE.[4]

Mustard has been used in Africa and China for thousands of years. Mustard greens have been popularly consumed in China. Yellow mustard paste originated in China during the Zhou Dynasty (1046–256 BCE) where the mustard seeds were ground and made into paste. It was often used in the royal courts during the Zhou Dynasty to help whet the appetite for the later courses in a meal.[5]

The Romans were probably the first to experiment with the preparation of mustard as a condiment. They mixed unfermented grape juice (the must) with ground mustard seeds (called sinapis) to make "burning must", mustum ardens—hence "must ard".[6] A recipe for mustard appears in De re coquinaria, the anonymously compiled Roman cookbook from the late fourth or early fifth century; the recipe calls for a mixture of ground mustard, pepper, caraway, lovage, grilled coriander seeds, dill, celery, thyme, oregano, onion, honey, vinegar, fish sauce, and oil, and was intended as a glaze for spit-roasted boar.[7]

The Romans likely exported mustard seed to Gaul, and by the 10th century, monks of Saint-Germain-desPrés in Paris absorbed the mustard-making knowledge of Romans[clarification needed] and began their own production.[8] The first appearance of mustard makers on the royal registers in Paris dates back to 1292.[9] Dijon, France, became a recognized center for mustard making by the 13th century.[8] The popularity of mustard in Dijon is evidenced by written accounts of guests consuming 320 litres (70 imp gal) of mustard creme in a single sitting at a gala held by the Duke of Burgundy in 1336.[10] In 1877, one of the most famous Dijon mustard makers, Grey-Poupon, was established as a partnership between Maurice Grey, a mustard maker with a unique recipe containing white wine; and Auguste Poupon, his financial backer.[11] Their success was aided by the introduction of the first automatic mustard-making machine.[11] In 1937, Dijon mustard was granted an Appellation d'origine contrôlée.[8] Due to its long tradition of mustard making, Dijon is regarded as the mustard capital of the world.[8]

The early use of mustard as a condiment in England is attested from the year 1390 in the book The Forme of Cury which was written by King Richard II's master cooks. It was prepared in the form of mustard balls—coarse-ground mustard seed combined with flour and cinnamon, moistened, rolled into balls, and dried—which were easily stored and combined with vinegar or wine to make mustard paste as needed.[12] The town of Tewkesbury was well known for its high-quality mustard balls, originally made with ground mustard mixed with horseradish and dried for storage,[13] which were then exported to London and other parts of the country, and are even mentioned in William Shakespeare's play King Henry the Fourth, Part II.[14]

The use of mustard as a hot dog condiment is said to have been first seen in the US at the 1904 St. Louis World's Fair, when the bright-yellow French's mustard was introduced by the R.T. French Company.[15]

Culinary uses

Catla fish (Indian freshwater carp) in authentic Bengali mustard gravy.

Indian freshwater carp in authentic Bengali mustard gravy

Mustard, yellow

Nutritional value per 100 g (3.5 oz)

Energy 276 kJ (66 kcal)

Carbohydrates

6 g

Sugars 3 g

Dietary fibre	3 g

Fat

3 g

Protein

4 g

Minerals	Quantity%DV†
Magnesium	11%48 mg
Potassium	5%152 mg

Sodium 49%1120 mg

†Percentages estimated using US recommendations for adults.[16]

Mustard is most often used at the table as a condiment on cold and hot meats.[17] It is also used as an ingredient in mayonnaise, vinaigrette, marinades, and barbecue sauce. It is also a popular accompaniment to hot dogs, pretzels, and bratwurst. In the Netherlands and Belgium, mustard is mainly used as a seasoning of croquettes, bitterballen and cheese, and commonly used to make mustard soup, which includes mustard, cream, parsley, garlic, and pieces of salted bacon.

Mustard as an emulsifier can stabilize a mixture of two or more immiscible liquids, such as oil and water.[18][19][20] Added to Hollandaise sauce, mustard can inhibit curdling.[21]

Mustard can be added to dishes as a primary spice, as is popular in East Indian cuisine. Added to mixed vegetables or fish curries, it can impart a unique flavor to some of the Indian recipes.

Nutritional value

The amounts of various nutrients in mustard seed are to be found in the USDA National Nutrient Database.[22] As a condiment, mustard averages about 5 kcal per teaspoon.[21] Some of the many vitamins and nutrients found in mustard seeds are selenium and omega 3 fatty acid.[23]

Preparation

The many varieties of prepared mustards have a wide range of strengths and flavors, depending on the variety of mustard seed and the preparation method. The basic taste and "heat" of the mustard are determined largely by seed type, preparation, and ingredients.[24][25] Preparations from the white mustard plant (Sinapis alba) have a less pungent flavor than preparations of black mustard (Brassica nigra) or brown mustard (Brassica juncea). The temperature of the water and concentration of acids such as vinegar also determine the strength of a prepared mustard; hotter liquids and stronger acids denature the enzymes that make the strength-producing compounds. Thus, "hot" mustard is made with cold water, whereas using hot water produces a milder condiment, all else being equal.[26]

Mustard oil can be extracted from the chaff and meal of the seed.

Flavors

The mustard plant itself has a sharp, hot, pungent flavor.

Mixing ground mustard seeds with water causes a chemical reaction between two compounds in the seed: the enzyme myrosinase and various glucosinolates such as sinigrin and sinalbin. The myrosinase enzyme turns the glucosinolates into various isothiocyanate compounds known generally as mustard oil.

The concentrations of different glucosinolates in mustard plant varieties, and the different isothiocyanates that are produced, make different flavors and intensities.

Allyl isothiocyanate and 4-hydroxybenzyl isothiocyanate are responsible for the sharp, hot, pungent sensation in mustards and in horseradish, wasabi, and garlic, because they stimulate the heat- and acidity-sensing TRPV ion channel TRPV1 on nociceptors (pain sensing nerve cell) in the mouth and nasal passages. The heat of prepared mustard can dissipate with time.[27] This is due to gradual chemical break-up of 4-hydroxybenzyl isothiocyanate.

Sulforaphane, phenethyl isothiocyanate, and benzyl isothiocyanate create milder and less pungent intensities and flavors as when found in broccoli, brussels sprouts, watercress, and cabbages.

The sulfoxide unit in sulforaphane is structurally similar to a thiol, which yields onion or garlic-like odours.

Prepared mustard condiment may also have ingredients giving salty, sour (vinegar), and sweet flavors. Turmeric is often added to commercially prepared mustards, mainly to give them a yellow color.

Storage and shelf life

Prepared mustard is sold in glass jars, plastic bottles, or metal squeeze tubes.[28] Because of its antibacterial properties and acidity, mustard does not require refrigeration for safety; it will not grow mold, mildew, or harmful bacteria.[29] Mustard can last indefinitely without becoming inedible or harmful, though it may dry out, lose flavor, or brown from oxidation.[29] Mixing in a small amount of wine or vinegar may improve dried-out mustard. Some types of prepared mustard stored for a long time may separate, which can be corrected by stirring or shaking. If stored unrefrigerated for a long time, mustard can acquire a bitter taste.[30]

When whole mustard seeds are crushed and mixed with a liquid, an enzyme is activated that releases pungent sulfurous compounds, but they quickly evaporate. An acidic liquid, such as wine or vinegar, produces longer-lasting flavor by slowing the reaction.[31] However prepared mustard loses its pungency over time; the loss can be slowed by keeping a sealed container (opaque or in the dark) in a cool place or refrigerator.[32]

Varieties

Mustards come in a wide variety of preparations which vary in the preparation of the mustard seeds and which other ingredients are included. The mustard seed husks may be ground with the seeds, or winnowed away after the initial crushing.

Locations renowned for their mustard include Dijon and Meaux in France; Norwich and (historically) Tewkesbury in England; and Düsseldorf, Bautzen, and Bavaria in Germany.

American yellow mustard

Plochman's mild yellow mustard, with typical bright yellow packaging

The most common mustard in the United States is known simply as "yellow mustard", a variety which has also become popular elsewhere since its introduction. Made entirely with the less-piquant yellow mustard seeds and a high proportion of vinegar, it is a very mild prepared mustard colored bright yellow from the inclusion of turmeric powder. It was introduced in 1904 by George J. French as "cream salad mustard". Yellow mustard is regularly used to top hot dogs, sandwiches, pretzels, and hamburgers. It is also an ingredient of many potato salads, barbecue sauces, and salad dressings. It is commonly referred to as "hot dog" or "ballpark" mustard because of its traditional popularity on hot dogs at baseball games.

"Deli-style" spicy brown mustard

Spicy brown mustard is also common in the United States. It includes some coarsely ground brown mustard seeds, giving it a speckled appearance and a spicier flavor than American yellow mustard. Some deli-style mustards also incorporate horseradish for additional heat. A variety popular in Louisiana is called Creole mustard, which is much coarser than most spicy brown types.

Dijon mustard

Dijon mustard exported to Bulgaria

Main article: Dijon mustard

Dijon mustard originated in 1856, when Jean Naigeon of Dijon replaced the usual ingredient of vinegar with verjuice, the acidic "green" juice of unripe grapes.[33] Most Dijon mustards today contain white wine rather than verjuice.

"Dijon mustard" is not a protected food name. While mustard factories still operate in Dijon and adjoining towns, most Dijon mustard is manufactured elsewhere.

English mustard

Prepared English mustard is bright yellow with a relatively thick consistency. It is made with a combination of yellow and brown seeds and is stronger than many other mustards as it has a low acid content. It is particularly suited to flavoring as a cooking ingredient but is also used as a table condiment for cold and hot meats. A woman based in Durham by the name of Mrs Clements was the first person to sell English mustard in a prepared format in 1720.[34] The most famous brand of English mustard is Colman's of Norwich. Colman's began by selling mustard powder in the company's trademark yellow tin, which it introduced in 1814.

"French" mustard

Not to be confused with French's mustard.

"French" mustard is a dark brown, mild, tangy and sweet mustard, that, despite its name, is not actually French in origin. French mustard is particular to the UK and was invented by Colman's in 1936.[35] It became a popular accompaniment to steak in particular. Colman's ceased production of French mustard in 2001 after Unilever, which now owns Colman's, were ordered to stop selling it by the EU, following its takeover of rival mustard-maker Amora–Maille in 2000.[36] Many British supermarkets still offer their own version of French mustard.

Fruit mustards

Fruit and mustard have been combined since the Lombard creation of mostarda di frutta in the 14th century.[10] Large chunks of fruit preserved in a sweet, hot mustard syrup were served with meat and game, and were said to be a favorite of the Dukes of Milan. Traditional variations of fruit mustards include apple mustard (traditional in Mantua and very hot), quince mostarda (or mostarda vicentina, mild and with a jam-like appearance), and cherry mustard. In various areas of Italy, the term mostarda refers to sweet condiments made with fruit, vegetables, and mosto, grape juice that gets simmered until syrupy.

Honey mustard

"Honey mustard" redirects here. For other uses, see Honey mustard (disambiguation).

Honey mustard is a blend of mustard and honey.[37] It is commonly used both on sandwiches and as a dip for finger foods such as chicken fingers. It can also be combined with vinegar or olive oil to make a salad dressing.

Hot mustard

The term "hot mustard" is used for mustards prepared to bring out the natural piquancy of the mustard seeds.[27] This is enhanced by using more pungent black or brown mustard seeds rather than yellow mustard seeds, and the low acidity of the liquid used.[27][38] Karashi is a variety of hot mustard originating in Japan. Hot mustard is also a common condiment in Chinese cuisine.[39][40]

Hot pepper mustard

Chilli peppers of various strengths are used to make a variety of mustards more piquant than plain mustard. Chilis or a hot sauce such as Sriracha made from chilis are added to mustards of different base styles such as yellow mustard, brown mustard, or spirit mustards.

Spirit mustards

Spirit mustards are made with alcoholic distilled spirits. Variations include Arran mustards with Scotch whisky, brandied peach mustard, cognac mustard, Irish "pub" mustard with Irish whiskey, and Jack Daniel's mustard.[41]

Sweet mustard

Romanian Tecuci mustard

Sweet mustard is sweetened with sugar. It is common in Bavaria where it is typically served with Weißwurst or Leberkäse. Moutarde douce is a sweetened mustard usually containing other herbs found in France, though less common than Dijon style. Other types of sweet mustards are known in Austria and Switzerland. Sweet mustard from Tecuci, Romania, is a variety very popular in Southeastern Europe and is suitable for grilled meats such as mititei.

Whole-grain mustard

Whole-grain mustard from France

In whole-grain mustard, also known as granary mustard, the seeds are mixed whole with other ingredients. Different flavors and strengths can be achieved through different blends of mustard seed species. Groningen mustard and others are examples of mustards with partially ground grains.

Home preparation

A method of preparing hot table mustard by the home cook is by mixing ground mustard powder to the desired consistency with water or an acidic liquid such as wine, vinegar, milk or beer, and letting it stand for 10 minutes.[42] It is usually prepared immediately before a meal; mustard prepared with water, in particular, is more pungent, but deteriorates rapidly.[31]

Allergies

A strong mustard can make the eyes water, and sting the tongue, palate, and throat. Home-made mustards may be hotter and more intensely flavored than most commercial preparations.[43]

Any part of the mustard plant can also, rarely, cause allergic reactions in some people, including anaphylaxis. In the European Union labeling the presence of mustard in packaged food is compulsory, either as an ingredient or even as unintended contamination in trace amounts. The Regulation (EC) 1169/2011[44] on food-labelling lists 14 allergens, including mustard, the presence of which in packaged food must be clearly indicated on the label as part of the list of ingredients, using a distinctive

Sesame

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"Black sesame" redirects here. For another "black sesame" crop plant of western and central Africa see Sesamum radiatum.

For other uses, see Sesame (disambiguation).

Sesame

A photograph of a sesame plant with glossy dark green leaves and a white flower

Sesame plants

Scientific classificationEdit this classification

Kingdom: Plantae

Clade: Tracheophytes

Clade: Angiosperms

Clade: Eudicots

Clade: Asterids

Order: Lamiales

Family: Pedaliaceae

Genus: Sesamum

Species: S. indicum

Binomial name

Sesamum indicum

L.

Synonyms[1]

Dysosmon amoenum Raf.

Sesamum africanum Tod.

Sesamum occidentalis Heer & Regel

Sesamum oleiferum Sm.

Sesamum orientale L.

Volkameria orientalis (L.) Kuntze

Sesame (/ˈsɛsəmi/;[2][3] Sesamum indicum) is a plant in the genus Sesamum, also called benne or gingelly.[4] Numerous wild relatives occur in Africa and a smaller number in India.[5] It is widely naturalized in tropical regions around the world and is cultivated for its edible seeds, which grow in pods. World production in 2018 was 6 million tonnes (5,900,000 long tons; 6,600,000 short tons), with Sudan, Myanmar, and India as the largest producers.[6]

Sesame seed is one of the oldest oilseed crops known, domesticated well over 3,000 years ago. Sesamum has many other species, most being wild and native to sub-Saharan Africa.[5] S. indicum, the cultivated type, originated in India.[7][5] It tolerates drought conditions well, growing where other crops fail.[8][9] Sesame has one of the highest oil contents of any seed. With a rich, nutty flavor, it is a common ingredient in cuisines around the world.[10][11] Like other foods, it can trigger allergic reactions in some people and is one of the nine most common allergens outlined by the Food and Drug Administration (FDA).[12][13]

Etymology

The word "sesame" is from Latin sesamum and Greek σήσαμον: sēsamon; which in turn are derived from ancient Semitic languages, e.g., Akkadian šamaššamu.[14] From these roots, words with the generalized meaning "oil, liquid fat" were derived.[15][16]

The word "benne" was first recorded to be used in English in 1769 and comes from Gullah benne which itself derives from Malinke běne.[17][4]

Origins and history

Sesame seed is considered to be the oldest oilseed crop known to humanity.[8] The genus has many species, and most are wild.[5] Most wild species of the genus Sesamum are native to sub-Saharan Africa.[5] S. indicum, the cultivated type,[7][18] originated in India.[15][19][5]

Archaeological remnants of charred sesame dating to about 3500-3050 BCE suggest sesame was domesticated in the Indian subcontinent at least 5500 years ago.[20][21] It has been claimed that trading of sesame between Mesopotamia and the Indian subcontinent occurred by 2000 BC.[22] It is possible that the Indus Valley civilization exported sesame oil to Mesopotamia, where it was known as ilu in Sumerian and ellu in Akkadian, compare Southern Dravidian Kannada eḷḷu, Tamil eḷ.[23]

Some reports claim sesame was cultivated in Egypt during the Ptolemaic period,[24][page needed] while others suggest the New Kingdom.[25][26] Egyptians called it sesemt, and it is included in the list of medicinal drugs in the scrolls of the Ebers Papyrus dated to be over 3600 years old. Excavations of King Tutankhamen uncovered baskets of sesame among other grave goods, suggesting that sesame was present in Egypt by 1350 BC.[27] Archeological reports indicate that sesame was grown and pressed to extract oil at least 2750 years ago in the empire of Urartu.[11][28][29] Others believe it may have originated in Ethiopia.[30]

Historically, sesame was favored for its ability to grow in areas that do not support the growth of other crops. It is also a robust crop that needs little farming support—it grows in drought conditions, in high heat, with residual moisture in soil after monsoons are gone or even when rains fail or when rains are excessive. It was a crop that could be grown by subsistence farmers at the edge of deserts, where no other crops grow. Sesame has been called a survivor crop.[9]

Botany

Flower of S. indicum

Sesame seed capsule

Flowers & Seed Capsules on Sesame Plant

Flowers and seed capsules on sesame plant

Sesame is a perennial plant growing 50 to 100 cm (1 ft 8 in to 3 ft 3 in) tall, with opposite leaves 4 to 14 cm (2 to 6 in) long with an entire margin; they are broad lanceolate, to 5 cm (2 in) broad, at the base of the plant, narrowing to just 1 cm (13⁄32 in) broad on the flowering stem. The flowers are tubular, 3 to 5 cm (1+1⁄8 to 2 in) long, with a four-lobed mouth. The flowers may vary in colour, with some being white, blue, or purple.

Sesame seeds occur in many colours depending on the cultivar. The most traded variety of sesame is offwhite coloured. Other common colours are buff, tan, gold, brown, reddish, gray, and black. The colour is the same for the hull and the fruit.[citation needed]

Sesame Eleusine coracana (L.) Gaertn. from the Seikei Zusetsu agriculture encyclopedia

Sesame fruit is a capsule, normally pubescent, rectangular in section, and typically grooved with a short, triangular beak. The length of the fruit capsule varies from 2 to 8 centimetres (3⁄4 to 3+1⁄8 in), its width varies between 0.5 and 2.0 centimetres (13⁄64 and 25⁄32 in), and the number of loculi varies from four to 12. The fruit naturally splits open (dehisces) to release the seeds by splitting along the septa from top to bottom or by means of two apical pores, depending on the varietal cultivar. The degree of dehiscence is of importance in breeding for mechanised harvesting, as is the insertion height of the first capsule.[citation needed]

Sesame seeds are small. Their sizes vary with the thousands of varieties known. Typically, the seeds are about 3 to 4 mm long by 2 mm wide and 1 mm thick (15⁄128 to 5⁄32 × 5⁄64 × 5⁄128). The seeds are ovate, slightly flattened, and somewhat thinner at the eye of the seed (hilum) than at the opposite end. The mass of 100 seeds is 0.203 g.[31] The seed coat (testa) may be smooth or ribbed.[citation needed]

Cultivation

Sesame varieties have adapted to many soil types. The high-yielding crops thrive best on well-drained, fertile soils of medium texture and neutral pH. However, these have a low tolerance for soils with high salt and water-logged conditions. Commercial sesame crops require 90 to 120 frost-free days. Warm conditions above 23 °C (73 °F) favor growth and yields. While sesame crops can grow in poor soils, the best yields come from properly fertilized farms.[11][32]

Initiation of flowering is sensitive to photoperiod and sesame variety. The photoperiod also affects the oil content in sesame seed; increased photoperiod increases oil content. The oil content of the seed is inversely proportional to its protein content.[11]

Sesame is drought-tolerant, in part due to its extensive root system. However, it requires adequate moisture for germination and early growth. While the crop survives drought and the presence of excess water, the yields are significantly lower in either condition. Moisture levels before planting and flowering affect yield the most.[11]

Most commercial cultivars of sesame are intolerant of water-logging. Rainfall late in the season prolongs growth and increases loss to dehiscence, when the seedpod shatters, scattering the seed. Wind can also cause shattering at harvest.[11]

Processing

Sesame seeds are protected by a capsule that bursts when the seeds are ripe. The time of this bursting, or "dehiscence", tends to vary, so farmers cut plants by hand and place them together in an upright position to continue ripening until all the capsules have opened. The discovery of an indehiscent mutant (analogous to nonshattering domestic grains) by Langham in 1943 began the work towards the development of a high-yielding, dehiscence-resistant variety. Although researchers have made significant progress in sesame breeding, harvest losses due to early dehiscence continue to limit domestic US production.[33] Agronomists in Israel are working on modern cultivars of sesame that can be harvested by mechanical means.[34]

Since sesame is a small, flat seed, it is difficult to dry it after harvest because the small seed makes the movement of air around the seed difficult. Therefore, the seeds need to be harvested as dry as possible and stored at 6% moisture or less. If the seed is too moist, it can quickly heat up and become rancid.[10]

After harvesting, the seeds are usually cleaned and hulled. In some countries, once the seeds have been hulled, they are passed through an electronic color-sorting machine that rejects any discolored seeds to ensure perfect color, because sesame seeds with consistent appearance are perceived to be of better quality by consumers, and sell for a higher price.[citation needed]

Immature or off-sized seeds are removed and used for sesame oil production.

Production and trade

Sesame seed production – 2020

Country	Production (tonnes)
Sudan	1,525,104
Myanmar	740,000
Tanzania	710,000
India	658,000
Nigeria	490,000
Global	6,803,824

Source: FAOSTAT of the United Nations[6]

In 2020, world production of sesame seeds was 7 million tonnes (6,900,000 long tons; 7,700,000 short tons), led by Sudan, Myanmar, and Tanzania (table).[6]

The white and other lighter-coloured sesame seeds are common in Europe, the Americas, West Asia, and the Indian subcontinent. The black and darker-coloured sesame seeds are mostly produced in China and Southeast Asia.[35]

In the United States most sesame is raised by farmers under contract to Sesaco, which also supplies proprietary seed.[36][37]

Trade

Japan is the world's largest sesame importer. Sesame oil, particularly from roasted seed, is an important component of Japanese cooking and traditionally the principal use of the seed. China is the secondlargest importer of sesame, mostly oil-grade. China exports lower-priced food-grade sesame seeds, particularly to Southeast Asia. Other major importers are the United States, Canada, the Netherlands, Turkey, and France.[citation needed]

Sesame seed is a high-value cash crop. Prices have ranged between US$800 and 1,700 per tonne (810 and 1,730/long ton) between 2008 and 2010.[38][39]

Sesame exports sell across a wide price range. Quality perception, particularly how the seed looks, is a major pricing factor. Most importers who supply ingredient distributors and oil processors only want to purchase scientifically treated, properly cleaned, washed, dried, colour-sorted, size-graded, and impurity-free seeds with a guaranteed minimum oil content (not less than 40%) packed according to international standards. Seeds that do not meet these quality standards are considered unfit for export and are consumed locally. In 2008, by volume, premium prices, and quality, the largest exporter was India, followed by Ethiopia and Myanmar.[10][40]

Nutritional information

Whole sesame seeds, dried[41]

Nutritional value per 100 grams

Energy 2,400 kJ (570 kcal)

Carbohydrates

23.4

Sugars 0.3

Dietary fiber 11.8

Fat

49.7

Saturated 7.0

Monounsaturated 18.8

Polyunsaturated 21.8

Protein

17.7

Vitamins	Quantity%DV†
Vitamin A	9 IU
Thiamine (B1)	66%0.79 mg
Riboflavin (B2)	19%0.25 mg
Niacin (B3)	28%4.52 mg
Vitamin B6	46%0.79 mg
Folate (B9)	24%97 μg
Vitamin C	0%0 mg
Vitamin E	2%0.25 mg

Minerals	Quantity%DV†
Calcium	75%975 mg
Iron	81%14.6 mg
Magnesium	84%351 mg
Phosphorus	50%629 mg
Potassium	16%468 mg
Sodium	0%11 mg
Zinc	71%7.8 mg

Other constituents	Quantity
Water	4.7 g

†Percentages estimated using US recommendations for adults.[42]

In a 100 g (3.5 oz) amount, dried whole sesame seeds provide 2,400 kilojoules (573 kcal) and are composed of 5% water, 23% carbohydrates (including 12% dietary fiber), 50% fat, and 18% protein. A typical serving would be a tablespoon (9 grams), so nutrient content and % Daily Value (%DV) per serving would be approximately one-tenth of what is shown in the table.

The byproduct that remains after oil extraction from sesame seeds, also called sesame oil meal, is rich in protein (35–50%) and is used as feed for poultry and livestock.[10][11][35]

As many seeds do, whole sesame seeds contain a significant amount of phytic acid, which is considered an antinutrient in that it binds to certain nutritional elements consumed at the same time, especially minerals, and prevents their absorption by carrying them along as they pass through the small intestine. Heating and cooking reduce the amount of the acid in the seeds.[43]

Health effects

A meta-analysis showed that sesame consumption produced small reductions in both systolic and diastolic blood pressure;[44] another demonstrated improvement in fasting blood glucose and hemoglobin A1c.[45] Sesame oil studies reported a reduction of oxidative stress markers and lipid peroxidation.[46]

Allergy

Main article: Sesame allergy

Sesame can trigger the same allergic reactions, including anaphylaxis, as seen with other food allergens.[12] A cross-reactivity exists between sesame and peanuts, hazelnuts and almonds.[12][47] In addition to food products derived from sesame seeds, such as tahini and sesame oil, persons with sesame allergies are encouraged to be aware of foods that may contain sesame, such as baked goods.[12][47][48] In addition to food sources, individuals allergic to sesame have been warned that a variety of non-food sources may also trigger a reaction to sesame, including cosmetics and skin-care products.[48]

Prevalence of sesame allergy is on the order of 0.1-0.2%, but higher in countries in the Middle East and Asia where consumption is more common as part of traditional diets.[12] In the United States, sesame allergy possibly affects 1.5 million individuals.[49][50]

Canada requires sesame labeling as an allergen.[48] In the European Union, identifying the presence of sesame, along with 13 other foods, either as an ingredient or an unintended contaminant in packaged food is compulsory.[51] In the United States, the "FASTER Act" was passed in April 2021, stipulating that labeling be mandatory,[13] to be in effect January 1, 2023, making it the ninth required food ingredient for which labeling is mandated within the United States.[52][53]

Chemical composition

Sesame seeds contain the lignans sesamolin, sesamin, pinoresinol, and lariciresinol.[54][55]

Contamination

Contamination by Salmonella, E.coli, pesticides, or other pathogens may occur in large batches of sesame seeds, such as in September 2020 when high levels of a common industrial compound, ethylene oxide, was found in a 250-tonne shipment of sesame seeds from India.[56][57] After detection in Belgium, recalls for dozens of products and stores were issued across the European Union, totaling some 50 countries.[56][57] Products with an organic certification were also affected by the contamination.[58] Regular governmental food inspection for sesame contamination, as for Salmonella and E. coli in tahini, hummus or seeds, has found that poor hygiene practices during processing are common sources and routes of contamination.[59]

Culinary use

See also: List of sesame seed dishes

Sesame seeds are a rich source of oil.

Sesame seed is a common ingredient in various cuisines. It is used whole in cooking for its rich, nutty flavour. Sesame seeds are sometimes added to bread, including bagels and the tops of hamburger buns. They may be baked into crackers, often in the form of sticks. In Sicily and France, the seeds are eaten on bread (ficelle sésame, sesame thread). In Greece, the seeds are also used in cakes.

Fast-food restaurants use buns with tops sprinkled with sesame seeds. About 75% of Mexico's sesame crop is purchased by McDonald's[60] for use in their sesame seed buns worldwide.[61]

Sesame seed cookies called Benne wafers, both sweet and savory, are popular in places such as Charleston, South Carolina.[62] Sesame seeds, also called benne, are believed to have been brought into 17th-century colonial America by enslaved West Africans.[63] The entirety of the sesame plant was used extensively in West African cuisine. The seeds were commonly used as a thickener in soups and puddings, or could be roasted and infused in water to produce a coffee-like drink.[27] Sesame oil made from the seeds could be used as a substitute for butter, finding use as a shortening for making cakes.[27]

Moreover, the leaves on mature plants, which are rich in mucilage, can be used as a laxative as well as a treatment for dysentery and cholera.[64] After arriving in North America, the plant was grown by slaves to serve as a subsistence staple as a nutritional supplement to their weekly rations.[65] Since then, it has become a part of various American cuisines.

In Caribbean cuisine, sugar and white sesame seeds are combined into a bar resembling peanut brittle and sold in stores and street corners, like Bahamian Benny cakes.[66]

In Asia, sesame seeds are sprinkled onto some sushi-style foods.[67] In Japan, whole seeds are found in many salads and baked snacks, and tan and black sesame seed varieties are roasted and used to make the flavouring gomashio. East Asian cuisines, such as Chinese cuisine, use sesame seeds and oil in some dishes, such as dim sum, sesame seed balls (Cantonese: jin deui), and the Vietnamese bánh rán. Sesame flavour (through oil and roasted or raw seeds) is also used to marinate meat and vegetables. Chefs in tempura restaurants blend sesame and cottonseed oil for deep-frying. Ground black sesame and rice form an edible paste when mixed with water, called zhimahu, a Chinese dessert and breakfast dish.

Sesame, or simsim as it is known in East Africa, is used in African cuisine. In Togo, the seeds are a main soup ingredient and in the Democratic Republic of the Congo and in the north of Angola, wangila is a dish of ground sesame, often served with smoked fish or lobster.

Sesame seeds and oil are used extensively in India. In most parts of the country, sesame seeds mixed with heated jaggery, sugar, or palm sugar are made into balls and bars similar to peanut brittle or nut clusters and eaten as snacks. In Manipur, black sesame is used in the preparation of chikki and coldpressed oil.

Sesame is a common ingredient in many Middle Eastern cuisines. Sesame seeds are made into a paste called tahini (used in various ways, including hummus bi tahini) and the Middle Eastern confection halvah. Ground and processed, the seed is also used in sweet confections. Sesame is also a common component of the Levantine spice mixture za'atar, popular throughout the Middle East.[68][69]

In Indian, Middle Eastern, and East Asian cuisines, popular confectionery is made from sesame mixed with honey or syrup and roasted into a sesame candy. In Japanese cuisine, goma-dofu is made from sesame paste and starch.

Mexican cuisine and Salvadoran cuisine refer to sesame seeds as ajonjolí. It is mainly used as a sauce additive, such as mole or adobo. It is often also used to sprinkle over artisan breads and baked in traditional form to coat the smooth dough, especially on whole-wheat flatbreads or artisan nutrition bars, such as alegrías.

Sesame oil is sometimes used as a cooking oil in different parts of the world, though different forms have different characteristics for high-temperature frying. The "toasted" form of the oil (as distinguished from the "cold-pressed" form) has a distinctive pleasant aroma and taste, and is used as a table condiment in some regions.

Gallery

Magnified image of white sesame seeds Magnified

image of white sesame seeds

Sesame seeds are commonly added to baked goods and creative confectionery Sesame

seeds are commonly added to baked goods and creative confectionery

Rolled khao phan with black sesame seeds Rolled

khao phan with black sesame seeds

Sesame seed breadsticks Sesame

seed breadsticks

Sesame sweet cake Sesame

sweet cake

Sesame seed ball confection Sesame

seed ball confection

Til-patti – a sesame brittle-type confection from India

Til-patti – a sesame brittle-type confection from India

Simit, koulouri, or gevrek, a ring-shaped bread coated with sesame seeds Simit,

koulouri, or gevrek, a ring-shaped bread coated with sesame seeds

Sesame flower, Behbahan Sesame

flower, Behbahan

Sesame flower in Behbahan Sesame

flower in Behbahan

Typical Israeli Bourekas with sesame seeds Typical

Israeli Bourekas with sesame seeds

In literature

Main article: Open sesame

In myths, the opening of the capsule releases the treasure of sesame seeds,[70] as applied in the story of "Ali Baba and the Forty Thieves" when the phrase "Open sesame" magically opens a sealed cave. Upon ripening, sesame pods split, releasing a pop and possibly indicating the origin of this phrase. typography (i.e. bold, capitals).

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This article is about the crop. For the comic strip, see Peanuts. For other uses, see Peanut (disambiguation).

"Arachis hypogaea" redirects here. For Peanut allergen powder, see Peanut allergen powder-dnfp.

"Goober peas" redirects here. For the folk song, see Goober Peas.

Peanut

Scientific classificationEdit this classification

Kingdom: Plantae

Clade: Tracheophytes

Clade: Angiosperms

Clade: Eudicots

Clade: Rosids

Order: Fabales

Family: Fabaceae

Subfamily: Faboideae

Genus: Arachis

Species: A. hypogaea

Binomial name

Arachis hypogaea

L.

Subspecies and varieties subsp. fastigiata

Waldron var. aequatoriana Krapov. & W. C.

Greg var. fastigiata (Waldron) Krapov. & W. C.

Greg var. peruviana Krapov. & W. C. Greg var.

vulgaris Harz subsp. hypogaea L. var. hirsuta

J. Kohler var. hypogaea L.

Synonyms[1]

Arachis nambyquarae Hoehne

Lathyrus esquirolii H. Lév.

The peanut (Arachis hypogaea), also known as the groundnut,[2] goober (US),[3] pindar (US)[3] or monkey nut (UK), is a legume crop grown mainly for its edible seeds. It is widely grown in the tropics and subtropics, important to both small and large commercial producers. It is classified as both a grain legume[4] and, due to its high oil content, an oil crop.[5] World annual production of shelled peanuts was 44 million tonnes in 2016, led by China with 38% of the world total. Atypically among legume crop plants, peanut pods develop underground (geocarpy) rather than above ground. With this characteristic in mind, the botanist Carl Linnaeus gave peanuts the specific epithet hypogaea, which means "under the earth".

The peanut belongs to the botanical family Fabaceae (or Leguminosae), commonly known as the legume, bean, or pea family.[1] Like most other legumes, peanuts harbor symbiotic nitrogen-fixing bacteria in root nodules.[6] The capacity to fix nitrogen means peanuts require less nitrogen-containing fertilizer and improve soil fertility, making them valuable in crop rotations.

The botanical definition of a nut is "a fruit whose ovary wall becomes hard at maturity." Using this criterion, the peanut is not a nut.[7] However, peanuts are usually categorized as nuts for culinary purposes and in common English more generally. Peanuts are similar in taste and nutritional profile to tree nuts such as walnuts and almonds, and, as a culinary nut, are often served in similar ways in Western cuisines.

Peanuts

History

The Arachis genus is native to South America, east of the Andes, around Peru, Bolivia, Argentina, and Brazil.[8] Cultivated peanuts (A. hypogaea) arose from a hybrid between two wild species of peanut, thought to be A. duranensis and A. ipaensis.[8][9][10] The initial hybrid would have been sterile, but spontaneous chromosome doubling restored its fertility, forming what is termed an amphidiploid or allotetraploid.[8] Genetic analysis suggests the hybridization may have occurred only once and gave rise to A. monticola, a wild form of peanut that occurs in a few limited locations in northwestern Argentina, or in southeastern Bolivia, where the peanut landraces with the most wild-like features are grown today,[11] and by artificial selection to A. hypogaea.[8][9]

The process of domestication through artificial selection made A. hypogaea dramatically different from its wild relatives. The domesticated plants are bushier, more compact, and have a different pod structure and larger seeds. From this primary center of origin, cultivation spread and formed secondary and tertiary centers of diversity in Peru, Ecuador, Brazil, Paraguay, and Uruguay. Over time, thousands of peanut landraces evolved; these are classified into six botanical varieties and two subspecies (as listed in the peanut scientific classification table). Subspecies A. h. fastigiata types are more upright in their growth habit and have shorter crop cycles. Subspecies A. h. hypogaea types spread more on the ground and have longer crop cycles.[11]

The oldest known archeological remains of pods have been dated at about 7,600 years old, possibly a wild species that was in cultivation, or A. hypogaea in the early phase of domestication.[12] They were found in Peru, where dry climatic conditions are favorable for the preservation of organic material. Almost certainly, peanut cultivation antedated this at the center of origin where the climate is moister. Many pre-Columbian cultures, such as the Moche, depicted peanuts in their art.[13] Cultivation was well-established in Mesoamerica before the Spanish arrived. There, the conquistadors found the tlālcacahuatl (the plant's Nahuatl name, hence the name in Spanish cacahuete) offered for sale in the marketplace of Tenochtitlan. Its cultivation was introduced in Europe in the 19th century through Spain, particularly Valencia, where it is still produced, albeit marginally.[14] European traders later spread the peanut worldwide, and cultivation is now widespread in tropical and subtropical regions. In West Africa, it substantially replaced a crop plant from the same family, the Bambara groundnut, whose seed pods also develop underground.[citation needed] In Asia, it became an agricultural mainstay, and this region is now the largest producer in the world.[15]

Peanuts were introduced to the US during the colonial period and grown as a garden crop. Starting in 1870 it was used as an animal feedstock until human consumption grew in the 1930s.[16] George Washington Carver (1864-1943) championed the peanut as part of his efforts for agricultural extension in the American South, where soils were depleted after repeated plantings of cotton. He invented and promulgated hundreds of peanut-based products, including cosmetics, taints, paints, plastics, gasoline and nitroglycerin.[17] The United States Department of Agriculture initiated a program to encourage agricultural production and human consumption of peanuts in the late 19th and early 20th centuries.[16]

Peanut butter was developed in the 1890s in the United States. It became well known after the Beech-Nut company began selling peanut butter at the St. Louis World's Fair of 1904.[18]

Composition

Nutrition

Peanut, valencia, raw

Nutritional value per 100 g (3.5 oz)

Energy 2,385 kJ (570 kcal)

Carbohydrates

21 g

Sugars 0.0 g

Dietary fiber 9 g

Fat

48 g

Saturated 7 g

Monounsaturated 24 g Polyunsaturated 16 g

Protein

25 g

Tryptophan 0.2445 g

Threonine 0.859 g

Isoleucine 0.882 g

Leucine 1.627 g

Lysine 0.901 g

Methionine 0.308 g

Cystine 0.322 g

Phenylalanine 1.300 g

Tyrosine 1.020 g

Valine 1.052 g

Arginine 3.001 g

Histidine 0.634 g

Alanine 0.997 g

Aspartic acid 3.060 g

Glutamic acid 5.243 g

Glycine 1.512 g

Proline 1.107 g

Serine 1.236 g

Vitamins Quantity%DV†

Thiamine (B1) 50%0.6 mg

Riboflavin (B2) 23%0.3 mg

Niacin (B3)	81%12.9 mg
Pantothenic acid (B5)	36%1.8 mg
Vitamin B6	18%0.3 mg
Folate (B9)	62%246 µg
Vitamin C	0%0.0 mg
Vitamin E	44%6.6 mg
Minerals	Quantity%DV†
Calcium	5%62 mg
Iron	11%2 mg
Magnesium	44%184 mg
Manganese	87%2.0 mg
Phosphorus	27%336 mg
Potassium	7%332 mg
Sodium	0%6 mg
Zinc	30%3.3 mg
Other constituents	Quantity
Water	4.26 g

Link to full USDA Database entry

†Percentages estimated using US recommendations for adults.[19]

Raw valencia peanuts are 4% water, 48% fat, 25% protein, and 21% carbohydrates, including 9% dietary fiber (right table, USDA nutrient data).

Peanuts are rich in essential nutrients. In a reference amount of 100-gram (3+1⁄2-ounce), peanuts provide 2,385 kilojoules (570 kilocalories) of food energy, and are an excellent source (defined as more than 20% of the Daily Value, DV) of several B vitamins, vitamin E, several dietary minerals, such as manganese (95% DV), magnesium (52% DV) and phosphorus (48% DV), and dietary fiber (right table). The fats are mainly polyunsaturated and monounsaturated (83% of total fats when combined).

Some studies show that regular consumption of peanuts is associated with a lower specific risk of mortality from certain diseases.[20][21] However, the study designs do not allow cause and effect to be inferred. According to the US Food and Drug Administration, "Scientific evidence suggests but does not prove that eating 1.5 ounces per day of most nuts (such as peanuts) as part of a diet low in saturated fat and cholesterol may reduce the risk of heart disease."[22]

Phytochemicals

Peanuts contain polyphenols, polyunsaturated and monounsaturated fats, phytosterols and dietary fiber in amounts similar to several tree nuts.[21]

Peanut skins contain resveratrol, which is under preliminary research for its potential effects on humans.[23][24]

Oil

A common cooking and salad oil, peanut oil is 46% monounsaturated fats (primarily oleic acid), 32% polyunsaturated fats (primarily linoleic acid), and 17% saturated fats (primarily palmitic acid).[25][26] Extractable from whole peanuts using a simple water and centrifugation method, the oil is being considered by NASA's Advanced Life Support program for future long-duration human space missions.[27]

Botany

Peanut flower

The peanut is an annual herbaceous plant growing 30 to 50 cm (12 to 20 in) tall.[16] As a legume, it belongs to the botanical family Fabaceae, also known as Leguminosae, and commonly known as the legume, bean, or pea family.[1] Like most other legumes, peanuts harbor symbiotic nitrogen-fixing bacteria in their root nodules.[6]

The leaves are opposite and pinnate with four leaflets (two opposite pairs; no terminal leaflet); each leaflet is 1 to 7 centimetres (1⁄2 to 2+3⁄4 in) long and 1 to 3 cm (1⁄2 to 1+1⁄4 in) across. Like those of many other legumes, the leaves are nyctinastic; that is, they have "sleep" movements, closing at night.

The flowers are 1 to 1.5 cm (3⁄8 to 5⁄8 in) across, and yellowish orange with reddish veining.[11][16] They are borne in axillary clusters on the stems above ground and last for just one day. The ovary is located at the base of what appears to be the flower stem but is a highly elongated floral cup.

Peanut fruits develop underground, an unusual feature known as geocarpy.[28] After fertilization, a short stalk at the base of the ovary—often termed a gynophore, but which appears to be part of the ovary—elongates to form a thread-like structure known as a "peg". This peg grows into the soil, allowing the fruit to develop underground.[28] These pods, technically called legumes, are 3 to 7 centimetres (1 to 3 in) long, normally containing one to four seeds.[11][16] The shell of the peanut fruit consists primarily of a mesocarp with several large veins traversing its length.[28]

Parts

Peanut seed separated showing the cotyledon, plumule and radicle

Parts of the peanut include:

Shell – outer covering, in contact with soil

Cotyledons (two) – the main edible part

Seed coat – brown paper-like covering of the edible part

Radicle – embryonic root at the bottom of the cotyledon, which can be snapped off

Plumule – embryonic shoot emerging from the top of the radicle

Toxicity

Allergies

Main article: Peanut allergy

Some people (0.6%[29] of the United States population) report that they experience allergic reactions to peanut exposure; symptoms are specifically severe for this nut and can range from watery eyes to anaphylactic shock, which is generally fatal if untreated. Eating a small amount of peanuts can cause a reaction. Because of their widespread use in prepared and packaged foods, avoiding peanuts can be difficult. Reading ingredients and warnings on product packaging is necessary to avoid this allergen. Foods processed in facilities that also handle peanuts on the same equipment as other foods are required to carry such warnings on their labels. Avoiding cross-contamination with peanuts and peanut products (along with other severe allergens like shellfish) is a promoted and common practice of which chefs and restaurants worldwide are becoming aware.

The hygiene hypothesis of allergy states that a lack of early childhood exposure to infectious agents like germs and parasites could be causing the increase in food allergies.[30]

Studies comparing age of peanut introduction in Great Britain with introduction in Israel showed that delaying exposure to peanuts in childhood can dramatically increase the risk of developing peanut allergies.[31][32]

Peanut allergy has been associated with the use of skin preparations containing peanut oil among children, but the evidence is not regarded as conclusive.[33] Peanut allergies have also been associated with family history and intake of soy products.[33]

Some school districts in the United States and elsewhere have banned peanuts or products containing peanuts.[34][35][36] However, the efficacy of the bans in reducing allergic reactions is uncertain. A 2015 study in Canada found no difference in the percentage of accidental exposures occurring in schools prohibiting peanuts compared to schools allowing them.[37]

Refined peanut oil will not cause allergic reactions in most people with peanut allergies.[38] However, crude (unrefined) peanut oils have been shown to contain protein, which may cause allergic reactions.[39] In a randomized, double-blind crossover study, 60 people with proven peanut allergy were challenged with both crude peanut oil and refined peanut oil. The authors concluded, "Crude peanut oil caused allergic reactions in 10% of allergic subjects studied and should continue to be avoided." They also stated, "Refined peanut oil does not seem to pose a risk to most people with peanut allergy." However, they point out that refined peanut oil can still pose a risk to peanut-allergic individuals if the oil that has previously been used for cooking foods containing peanuts is reused.[40]

Varieties

Cultivars in the United States

There are many peanut cultivars grown around the world. The market classes grown in the United States are Spanish, Runner, Virginia, and Valencia.[41] Peanut production in the United States is divided into three major areas: the southeastern United States region which includes Alabama, Georgia, and Florida; the southwestern United States region which includes New Mexico, Oklahoma, and Texas; and the third region in the general eastern United States which includes Virginia, North Carolina, and South Carolina.[41] In Georgia, Naomi Chapman Woodroof is responsible for developing the breeding program of peanuts resulting in a harvest almost five times greater.[42]

Certain cultivar groups are preferred for particular characteristics, such as differences in flavor, oil content, size, shape, and disease resistance.[43] Most peanuts marketed in the shell are of the Virginia type, along with some Valencias selected for large size and the attractive appearance of the shell. Spanish peanuts are used mostly for peanut candy, salted nuts, and peanut butter.

Spanish group

The small Spanish types are grown in South Africa and the southwestern and southeastern United States. Until 1940, 90% of the peanuts grown in the US state of Georgia were Spanish types, but the trend since then has been larger-seeded, higher-yielding, more disease-resistant cultivars. Spanish peanuts have a higher oil content than other types of peanuts. In the United States, the Spanish group is primarily grown in New Mexico, Oklahoma, and Texas.[41]

Cultivars of the Spanish group include 'Dixie Spanish', 'Improved Spanish 2B', 'GFA Spanish', 'Argentine', 'Spantex', 'Spanette', 'Shaffers Spanish', 'Natal Common (Spanish)', "White Kernel Varieties', 'Starr', 'Comet', 'Florispan', 'Spanhoma', 'Spancross', 'OLin', 'Tamspan 90', 'AT 9899–14', 'Spanco', 'Wilco I', 'GG 2', 'GG 4', 'TMV 2', and 'Tamnut 06'.

Runner group

Since 1940, the southeastern US region has seen a shift to producing Runner group peanuts. This shift is due to good flavor, better roasting characteristics, and higher yields when compared to Spanish types, leading to food manufacturers' preference for the use in peanut butter and salted nuts. Georgia's production is now almost 100% Runner-type.[43]

Cultivars of Runners include 'Southeastern Runner 56-15', 'Dixie Runner', 'Early Runner', 'Virginia Bunch 67', 'Bradford Runner', 'Egyptian Giant' (also known as 'Virginia Bunch' and 'Giant'), 'Rhodesian Spanish Bunch' (Valencia and Virginia Bunch), 'North Carolina Runner 56-15', 'Florunner', 'Virugard', 'Georgia Green', 'Tamrun 96', 'Flavor Runner 458', 'Tamrun OL01', 'Tamrun OL02' 'AT-120', 'Andru-93', 'Southern Runner', 'AT1-1', 'Georgia Brown', 'GK-7', and 'AT-108'.

Virginia group

The large-seeded Virginia group peanuts are grown in the US states of Virginia, North Carolina, Tennessee, Texas, New Mexico, Oklahoma, and parts of Georgia. They are increasing in popularity due to the demand for large peanuts for processing, particularly for salting, confections, and roasting in shells.

Virginia group peanuts are either bunch or running in growth habit. The bunch type is upright to spreading. It attains a height of 45 to 55 cm (18 to 22 in), and a spread of 70 to 80 cm (28 to 31 in), with 80 to 90 cm (31 to 35 in) rows that seldom cover the ground. The pods are borne within 5 to 10 cm (2 to 4 in) of the base of the plant.

Cultivars of Virginia-type peanuts include 'NC 7', 'NC 9', 'NC 10C', 'NC-V 11', 'VA 93B', 'NC 12C', 'VA-C 92R', 'Gregory', 'VA 98R', 'Perry', 'Wilson, 'Hull', 'AT VC-2' and 'Shulamit'.

Valencia group

Valencia peanuts

Valencia group peanuts are coarse and have heavy reddish stems and large foliage. In the United States, large commercial production is primarily in the South Plains of West Texas and in eastern New Mexico near and south of Portales, but they are grown on a small scale elsewhere in the South as the bestflavored and preferred type for boiled peanuts. They are comparatively tall, reaching a height of 125 cm (49 in) and a spread of 75 cm (30 in). Peanut pods are borne on pegs arising from the main stem and the side branches. Most pods are clustered around the base of the plant, and only a few are found several inches away. Valencia types are three- to five-seeded and smooth, with no constriction of the shell between the seeds. Seeds are oval and tightly crowded into the pods. Typical seed weight is 0.4 to 0.5 g. This type is used heavily for selling roasted and salted in-shell peanuts and peanut butter. Varieties include 'Valencia A' and 'Valencia C'.

Tennessee Red and Tennessee White groups

These are alike except for the color of the seed. Sometimes known also as Texas Red or White, the plants are similar to Valencia types, except the stems are green to greenish brown, and the pods are rough, irregular, and have a smaller proportion of kernels.

Uses

Culinary

See also: List of peanut dishes

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Whole peanuts

Roasted peanuts as snack food

Dry-roasting peanuts is a common form of preparation. Dry peanuts can be roasted in the shell or shelled in a home oven if spread out one layer deep in a pan and baked at a temperature of 177 °C (351 °F) for 15 to 20 min (shelled) and 20 to 25 min (in shell).

Boiled peanuts are a popular snack in India, China, West Africa, and the southern United States. In the US South, boiled peanuts are often prepared in briny water and sold in streetside stands.

A distinction can be drawn between raw and green peanuts. A green peanut is a term to describe farmfresh harvested peanuts that have not been dehydrated. They are available from grocery stores, food distributors, and farmers markets during the growing season. Raw peanuts are also uncooked but have been dried/dehydrated and must be rehydrated before boiling (usually in a bowl full of water overnight). Once rehydrated, the raw peanuts are ready to be boiled.[44]

Peanut oil

Main article: Peanut oil

Peanut oil

Peanut oil is often used in cooking because it has a mild flavor and a relatively high smoke point. Due to its high monounsaturated content, it is considered more healthful than saturated oils and is resistant to rancidity. The several types of peanut oil include aromatic roasted peanut oil, refined peanut oil, extra virgin or cold-pressed peanut oil, and peanut extract. Refined peanut oil is exempt from allergen labeling laws in the United States.[45]

Peanut butter

Main article: Peanut butter

Peanut butter

Peanut butter is a food paste or spread made from ground dry roasted peanuts. It often contains additional ingredients that modify the taste or texture, such as salt, sweeteners, or emulsifiers. Many companies have added twists on traditionally plain peanut butter by adding various flavor varieties, such as chocolate, birthday cake, and cinnamon raisin.[46] Peanut butter is served as a spread on bread, toast or crackers, and used to make sandwiches (notably the peanut butter and jelly sandwich). It is also used in a number of confections, such as peanut-flavored granola bars or croissants and other pastries. The United States[47] is a leading exporter of peanut butter, and itself consumes $800 million of peanut butter annually.[48]

Peanut flour

Main article: Peanut flour

Peanut flour is used in gluten-free cooking.

Peanut proteins

Peanut protein concentrates and isolates are commercially produced from defatted peanut flour using several methods. Peanut flour concentrates (about 70% protein) are produced from dehulled kernels by removing most of the oil and the water-soluble, non-protein components. Hydraulic pressing, screw pressing, solvent extraction, and pre-pressing followed by solvent extraction may be used for oil removal, after which protein isolation and purification are implemented.[49]

Latin America

Peanuts are particularly common in Peruvian and Mexican cuisine, both of which marry indigenous and European ingredients. For instance, in Peru, a popular traditional dish is picante de cuy,[50] a roasted guinea pig served in a sauce of ground peanuts (ingredients native to South America) with roasted onions and garlic (ingredients from European cuisine). Also, in the Peruvian city of Arequipa, a dish called ocopa consists of a smooth sauce of roasted peanuts and hot peppers (both native to the region) with roasted onions, garlic, and oil, poured over meat or potatoes.[51] Another example is a fricassee combining a similar mixture with sautéed seafood or boiled and shredded chicken. These dishes are generally known as ajíes, meaning "hot peppers", such as ají de pollo and ají de mariscos (seafood ajíes may omit peanuts). In Mexico, it is also used to prepare different traditional dishes, such as chicken in peanut sauce (encacahuatado), and is used as the main ingredient for the preparation of other famous dishes such as red pipián, mole poblano and oaxacan mole negro. [52]

Likewise, during colonial times in Peru, the Spanish used peanuts to replace nuts unavailable locally but used extensively in Spanish cuisine, such as almonds and pine nuts, typically ground or as a paste mixed with rice, meats, and vegetables for dishes like rice pilaf.

Throughout the region, many candies and snacks are made using peanuts. In Mexico, it is common to find them in different presentations as a snack or candy: salty, "Japanese" peanuts, praline, enchilados or in the form of a traditional sweet made with peanuts and honey called palanqueta, and even as peanut marzipan. There is a similar form of peanut candy in Brazil, called pé-de-moleque, made with peanuts and molasses, which resembles the Indian chikki in form.[53]

West Asia

See also: Israeli sweets and snack foods

Crunchy coated peanuts, called kabukim in Hebrew, are a popular snack in Israel. Kabukim are commonly sold by weight at corner stores where fresh nuts and seeds are sold, though they are also available packaged. The coating typically consists of flour, salt, starch, lecithin, and sometimes sesame seeds. The origin of the name is obscure (it may be derived from kabuk, which means nutshell or husk in Turkish). An additional variety of crunchy coated peanuts popular in Israel is "American peanuts". The coating of this variety is thinner but harder to crack.

Bamba puffs are a popular snack in Israel. Their shape is similar to Cheez Doodles, but they are made of peanuts and corn.

Southeast Asia

Fried peanuts in the Philippines

Peanuts are also widely used in Southeast Asian cuisine, such as in Malaysia, Vietnam, and Indonesia, where they are typically made into a spicy sauce. Peanuts came to Indonesia from the Philippines, where the legume was derived from Mexico during Spanish colonization. One Philippine dish using peanuts is kare-kare, a mixture of meat and peanut butter. Apart from being used in dishes, fried shelled peanuts are a common inexpensive snack in the Philippines. The peanuts are commonly served plain salted with garlic chips and variants, including adobo and chili flavors.

Common Indonesian peanut-based dishes include gado-gado, pecel, karedok, and ketoprak, vegetable salads mixed with peanut sauce, and the peanut-based sauce, satay.

Indian subcontinent

Boiled groundnuts (peanuts)

In the Indian subcontinent, peanuts are a light snack, usually roasted and salted (sometimes with the addition of chilli powder), and often sold roasted in pods or boiled with salt. They are also made into dessert or sweet snack of peanut brittle by processing with refined sugar and jaggery. Indian cuisine uses roasted, crushed peanuts to give a crunchy body to salads; they are added whole (without pods) to leafy vegetable stews for the same reason. Another use is peanut oil for cooking. Most Indians use mustard, sunflower, and peanut oil for cooking. In South India, groundnut chutney is eaten with dosa and idli as breakfast. Peanuts are also used in sweets and savory items in South India and also as a flavor in tamarind rice. Kovilpatti is known for its sweet peanut chikki or peanut brittle, which is also used in savory and sweet mixtures, such as Bombay mix.

West Africa

Peanuts grow well in southern Mali and adjacent regions of the Ivory Coast, Burkina Faso, Ghana, Nigeria, and Senegal; peanuts are similar in both agricultural and culinary qualities to the Bambara groundnut native to the region, and West Africans have adopted the crop as a staple. Peanut sauce, prepared with onions, garlic, peanut butter/paste, and vegetables such as carrots, cabbage, and cauliflower, can be vegetarian (the peanuts supplying ample protein) or prepared with meat, usually chicken.

Peanuts are used in the Malian meat stew maafe. In Ghana, peanut butter is used for peanut butter soup nkate nkwan.[54] Crushed peanuts may also be used for peanut candies nkate cake and kuli-kuli, as well as other local foods such as oto.[54] Peanut butter is an ingredient in Nigeria's "African salad". Peanut powder is an important ingredient in the spicy coating for kebabs (Suya) in Nigeria and Ghana.

East Africa

Peanuts are a common ingredient of several types of relishes (dishes which accompany nshima) eaten in Malawi, and in the eastern part of Zambia, and these dishes are common throughout both countries. Thick peanut butter sauces are also made in Uganda to serve with rice and other starchy foods. Groundnut stew, called ebinyebwa in Luganda-speaking areas of Uganda, is made by boiling ground peanut flour with other ingredients, such as cabbage, mushrooms, dried fish, meat or other vegetables.[55] Across East Africa, roasted peanuts, often in cones of newspaper, are obtained from street vendors.

North America

Fried curry peanuts

The state of Georgia leads the United States in peanut production, with 49 percent of the nation's peanut acreage and output. In 2014, farmers cultivated 591,000 acres of peanuts, yielding of 2.4 billion pounds. The most famous peanut farmer was Jimmy Carter of Sumter County, Georgia who became U.S. president in 1976.[56]

In the United States and Canada, peanuts are used in candies, cakes, cookies, and other sweets. Individually, they are eaten dry-roasted with or without salt. Ninety-five percent of Canadians eat peanuts or peanut butter, with the average consumption of 3 kilograms (6+1⁄2 lb) of peanuts per person annually, and 79% of Canadians consume peanut butter weekly.[57] In the United States, peanuts and peanut butter are central to American dietary practices, and are typically considered as comfort foods.[58] Peanuts were sold at fairs or by pushcart operators through the 19th century.[59] Peanut butter is a common peanut-based food, representing half of the American total peanut consumption and $850 million in annual retail sales.[60] Peanut soup is found on restaurant menus in the southeastern states.[61] In some southern portions of the US, peanuts are boiled for several hours until soft and moist.[62] Peanuts are also deep-fried, sometimes within the shell. Per person, Americans eat 2.7 kg (6 lb) of peanut products annually, spending a total of $2 billion in peanut retail purchases.[60]

Manufacturing

Production

Peanut production, 2020

(millions of tonnes)

Country	Production
China	18.0
India	10.0
Nigeria	4.5
United States	2.8
Sudan	2.8
World	53.6

Source: FAOSTAT, United Nations[15]

In 2020, world production of peanuts (reported as groundnuts in shells) was 54 million tonnes, an 8% increase over 2019 production.[15] China had 34% of global production, followed by India (19%) (table). Other significant producers were Nigeria, the United States, and Sudan.[15]

Industrial

Peanuts have a variety of industrial end uses. Paint, varnish, lubricating oil, leather dressings, furniture polish, insecticides, and nitroglycerin are made from peanut oil. Soap is made from saponified oil, and many cosmetics contain peanut oil and its derivatives. The protein portion is used in the manufacture of some textile fibers. Peanut shells are used in the manufacture of plastic, wallboard, abrasives, fuel, cellulose (used in rayon and paper), and mucilage (glue).

Malnutrition

Peanuts are used to help fight malnutrition. Plumpy Nut, MANA Nutrition,[63] and Medika Mamba[64] are high-protein, high-energy, and high-nutrient peanut-based pastes developed to be used as a therapeutic food to aid in famine relief. The World Health Organization, UNICEF, Project Peanut Butter, and Doctors Without Borders have used these products to help save malnourished children in developing countries.

Peanuts can be used like other legumes and grains to make a lactose-free, milk-like beverage, peanut milk, which is promoted in Africa as a way to reduce malnutrition among children.

Animal feed

Peanut plant tops and crop residues can be used for hay.[65]

The protein cake (oilcake meal) residue from oil processing is used as animal feed and soil fertilizer. Groundnut cake is a livestock feed, mostly used by cattle as protein supplements.[66] It is one of the most important and valuable feeds for all types of livestock and one of the most active ingredients for poultry rations.[67] Poor storage of the cake may sometimes result in its contamination by aflatoxin, a naturally occurring mycotoxin that is produced by Aspergillus flavus and Aspergillus parasiticus.[68] The major constituents of the cake are essential amino acids such as lysine and glutamine. Other components are crude fiber, crude protein, and fat.[citation needed]

Some peanuts can also be fed whole to livestock, for example, those over the peanut quota in the US or those with a higher aflatoxin content than that permitted by the food regulations.[69]

Peanut processing often requires dehulling: the hulls generated in large amounts by the peanut industries can feed livestock, particularly ruminants.[70]

Cultivation

Peanut pegs growing into the soil. The tip of the peg, once buried, swells and develops into a peanut fruit.

Peanuts grow best in light, sandy loam soil with a pH of 5.9–7. Their capacity to fix nitrogen means that providing they nodulate properly, peanuts benefit little or not at all from nitrogen-containing fertilizer,[71] and they improve soil fertility. Therefore, they are valuable in crop rotations. Also, the yield of the peanut crop itself is increased in rotations through reduced diseases, pests, and weeds. For example, in Texas, peanuts in a three-year rotation with corn yield 50% more than nonrotated peanuts.[71] Adequate levels of phosphorus, potassium, calcium, magnesium, and micronutrients are also necessary for good yields.[71] Peanuts need warm weather throughout the growing season to develop well. They can be grown with as little as 350 mm (14 in) of water,[72] but for best yields need at least 500 mm (20 in).[73] Depending on growing conditions and the cultivar of peanut, harvest is usually 90 to 130 days after planting for subspecies A. h. fastigiata types, and 120 to 150 days after planting for subspecies A. h. hypogaea types.[72][74][75] Subspecies A. h. hypogaea types yield more and are usually preferred where the growing seasons are sufficiently long.

Cultivation of peanut crop at the Indian Directorate of Groundnut Research (Junagadh, Gujarat, 2009)

Peanut plants continue to produce flowers when pods are developing; therefore, some pods are immature even when they are ready for harvest. To maximize yield, the timing of harvest is important. If it is too early, too many pods will be unripe; if too late, the pods will snap off at the stalk and remain in the soil.[76] For harvesting, the entire plant, including most of the roots, is removed from the soil.[76] The pods are covered with a network of raised veins and are constricted between seeds.

The main yield-limiting factors in semiarid regions are drought and high-temperature stress. The stages of reproductive development before flowering, at flowering, and at early pod development are particularly sensitive to these constraints. Apart from nitrogen, phosphorus and potassium, other nutrient deficiencies causing significant yield losses are calcium, iron and boron. Biotic stresses mainly include pests, diseases, and weeds. Among insects pests, pod borers, aphids, and mites are of importance. The most important diseases are leaf spots, rusts, and the toxin-producing fungus Aspergillus.[77]

Harvest of peanuts (Bandjoun, Cameroon, 2016)

Harvesting occurs in two stages.[43][self-published source?] In mechanized systems, a machine is used to cut off the main root of the peanut plant by cutting through the soil just below the level of the peanut pods. The machine lifts the "bush" from the ground, shakes it, then inverts it, leaving the plant upside down to keep the peanuts out of the soil. This allows the peanuts to dry slowly to a little less than a third of their original moisture level over three to four days. Traditionally, peanuts were pulled and inverted by hand.

After the peanuts have dried sufficiently, they are threshed, removing the peanut pods from the rest of the bush.[76] peanuts must be dried properly and stored in dry conditions. If they are too high in moisture, or if storage conditions are poor, they may become infected by the mold fungus Aspergillus flavus. Many strains of this fungus release toxic and highly carcinogenic substances called aflatoxins.

Pests and diseases

If peanut plants are subjected to severe drought during pod formation, or if pods are not properly stored, they may become contaminated with the mold Aspergillus flavus which may produce carcinogenic substances called aflatoxins. Lower-quality peanuts, particularly where mold is evident, are more likely to be contaminated.[78] The United States Department of Agriculture tests every truckload of raw peanuts for aflatoxin; any containing aflatoxin levels of more than 15 parts per billion are destroyed. The peanut industry has manufacturing steps to ensure all peanuts are inspected for aflatoxin.[79] Peanuts tested to have high aflatoxin are used to make peanut oil where the mold can be removed.[80]

The plant leaves can also be affected by a fungus,

Alternari

Contents hide

Pigeon pea

From Wikipedia, the free encyclopedia

Pigeon pea

Botanical illustration of the morphological details of a C. cajan specimen.

Botanical image depicting the foliage characteristics and differing pod and flower phenotypes.

Scientific classificationEdit this classification

Kingdom: Plantae

Clade: Tracheophytes

Clade: Angiosperms

Clade: Eudicots

Clade: Rosids

Order: Fabales

Family: Fabaceae

Subfamily: Faboideae

Genus: Cajanus

Species: C. cajan

Binomial name

Cajanus cajan

(L.) Huth

The pigeon pea[1] (Cajanus cajan) is a perennial legume from the family Fabaceae native to the Eastern Hemisphere.[2] The pigeon pea is widely cultivated in tropical and semitropical regions around the world, being commonly consumed in South Asia, Southeast Asia, Africa, Latin America and the Caribbean.[3]: 5941

Etymology and other names

Botanical inscription of C. cajan from Hendrik van Rheede transcribed in Devanagari, Malayalam, Arabic and the Latin alphabet from "Hortus Malabaricus" (1686).[4]

Scientific epithet

The scientific name for the genus Cajanus and the species cajan derive from the Malay word katjang (modern spelling: kacang) meaning legume in reference to the bean of the plant.[5]

Common English names

In English they are commonly referred to as pigeon pea which originates from the historical utilization of the pulse as pigeon fodder in Barbados.[6][7] The term Congo pea and Angola pea developed due to the presence of its cultivation in Africa and the association of its utilization with those of African descent.[8][9] The names no-eye pea and red gram both refer to the characteristics of the seed, with noeye pea in reference to the lack of a hilum blotch on most varieties, unlike the black-eyed pea, and red gram in reference to the red color of most Indian varieties and gram simply referring to the plant being a legume.[10]

Internationally

Africa

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In Benin the pigeon pea is locally known as klouékoun in Fon, otinin in Ede and eklui in Adja.[11][12] In Cape Verde they are called Fixon Kongu in Cape Verdean creole.[13] In Comoros and Mauritius they are known as embrevade or ambrebdade in Comorian[14] and Morisyen, respectively, in return originating from the Malagasy term for the plant amberivatry.[15] In Ghana they are known as aduwa or adowa in Dagbani.[16][17] In Kenya and Tanzania they are known as mbaazi in Swahili.[18] In Malawi they are called nandolo in Chichewa.[19] In Nigeria pigeon peas are called fiofio or mgbụmgbụ in Igbo,[20][21] waken-masar "Egyptian bean"[22] or waken-turawa "foreigner bean"[23] in Hausa,[24] and otinli in Yoruba.[25] In Sudan they are known as adaseya, adasy and adasia.[26][27]

Asia

Pigeon peas displayed next to a ruler from the Ereke market in Buton Island, Indonesia

In India the plant is known by various different names such as; Assamese: ৰহৰ মাহ (rohor mah), মমমৰ মাহ (miri-mah) • Bengali: অড়হর (arahar) • Gujarati: તુવેર (tuver) • Hindi: अरहर (arhar), तुवर (tuvar) • Kannada: ತೊಗರಿ ಬೆಳೆ (togari bele), ತೊಗರಿ ಕಾಳು (togari kalu) • Konkani: तोरी (tori) • Malayalam: ആഢകി (adhaki), തുവര (tuvara) • Manipuri: মাইৰোংবী (mairongbi) • Marathi: तूर (tur) • Nepali: रहर (rahar) • Oriya: ହର୍ ହର୍ (har-har), କାକ୍ଷୀ (kakshi), ତୁବର (tubara) • Persian: شاخول (shakhul) • Punjabi: ਦ ਿੰਗੇਰ (dinger) • Tamil: ஆடகி (adhaki), இருப்புலி (iruppuli), காய்சசி (kaycci), and துவரை (tuvarai) • Telugu: ఆఢకి (adhaki), కంది (kandi), తొగరి (togari), తువరము (tuvaramu) • Tibetan: tu ba ri and in Urdu: ارهر (arhar), توأر (tuar).[28][29]

In the Philippines they are known as Kadios in Filipino and Kadyos in Tagalog.[30][31]

The Americas

In Latin America,[32] they are known as guandul or gandul in Spanish, and feijão andu or gandu in Portuguese all of which derive from Kikongo wandu or from Kimbundu oanda; both names referring to the same plant.[33][34][35][36]

In the Anglophone regions of the Caribbean, like Jamaica,[37] they are known as Gungo peas, coming from the more archaic English name for the plant congo pea, given to the plant because of its popularity and relation to Sub-Saharan Africa.[38][39]

In Francophone regions of the Caribbean they are known as pois d' angole,[40] pwa di bwa in Antillean creole[41] and pwa kongo in Haitian creole.[42]

In Suriname they are known as wandoe[43] or gele pesi,[44] the former of which is derived from the same source as its Spanish and Portuguese counterparts, the latter of which literally translates to 'yellow pea' from Dutch and Sranan Tongo.

Oceania

In Hawaii they are known as pi pokoliko 'Puerto Rican pea' or pi nunu 'pigeon pea' in the Hawaiian language.[45]

History and origin

Pigeon pea flowers

Pollen grains of Pigeon pea

Origin

The closest relatives to the cultivated pigeon pea are Cajanus cajanifolia, Cajanus scarabaeoides and Cajanus kerstingii, native to India and the latter West Africa respectively.[46][47][48] Much debate exist over the geographical origin of the species, with some groups claiming origin from the Nile river and Western Africa, and the other Indian origin.[49] The two epicenters of genetic diversity exist in both

Africa and India, but India is considered to be its primary center of origin with West Africa being considered a second major center of origin.[50]

History

By at least 2,800 BCE in peninsular India,[51] where its presumptive closest wild relatives Cajanus cajanifolia occurs in tropical deciduous woodlands, its cultivation has been documented.[52] Archaeological finds of pigeon pea cultivation dating to about 14th century BC have also been found at the Neolithic site of Sanganakallu in Bellary and its border area Tuljapur (where the cultivation of African domesticated plants like pearl millet, finger millet, and Lablab have also been uncovered),[53] as well as in Gopalpur and other South Indian states.[54]

From India it may have made its way to North-East Africa via Trans-Oceanic Bronze Age trade that allowed cross-cultural exchange of resources and agricultural products. [55] The earliest evidence of pigeon peas in Africa was found in Ancient Egypt with the presence of seeds in Egyptian tombs dating back to around 2,200 BCE. [56] From eastern Africa, cultivation spread further west and south through the continent, where by means of the Trans-Atlantic slave trade, it reached the Americas around the 17th century.[39]

Pigeon peas were introduced to Hawaii in 1824 by James Macrae with a few specimens becoming naturalized on the islands, but they wouldn't gain much popularity until later.[57] By the early 20th century Filipinos and Puerto Ricans began to emigrate from the American Philippines and Puerto Rico to Hawaii to work in sugarcane plantations in 1906 and 1901, respectively.[58][59][60] Pigeon peas are said to have been popularized on the island by the Puerto Rican community where by the First World War their cultivation began, to expand on the island where they are still cultivated and consumed by locals.[61]

Nutrition

Pigeon peas, immature, raw

Pigeon peas in Trinidad and Tobago

Nutritional value per 100 g (3.5 oz)

Energy 569 kJ (136 kcal)

Carbohydrates

23.88 g

Sugars 3 g

Dietary fiber 5.1 g

Fat

1.64 g

Protein

7.2 g

Vitamins Quantity%DV†

Thiamine (B1) 33%0.4 mg

Riboflavin (B2) 13%0.17 mg

Niacin (B3) 14%2.2 mg

Pantothenic acid (B5) 14%0.68 mg

Vitamin B6 4%0.068 mg

Folate (B9) 43%173 µg

Choline 8%45.8 mg

Vitamin C 43%39 mg

Vitamin E 3%0.39 mg

Vitamin K 20%24 µg

Minerals Quantity%DV†

Calcium 3%42 mg

Iron 9%1.6 mg

Magnesium 16%68 mg

Manganese 25%0.574 mg

Phosphorus 10%127 mg

Potassium 18%552 mg

Sodium 0%5 mg

Zinc 9%1.04 mg

Link to USDA Database entry

Values for Choline, Vit. E/K available

†Percentages estimated using US recommendations for adults.[62]

Pigeon peas, mature, raw

Seeds of the pigeon pea

Nutritional value per 100 g (3.5 oz)

Energy 1,435 kJ (343 kcal)

Carbohydrates

62.78 g

Sugars n/a
Dietary fiber 15 g

Fat

1.49 g

Protein

21.7 g

Tryptophan 212 mg

Threonine 767 mg

Isoleucine 785 mg

Leucine 1549 mg

Lysine 1521 mg

Methionine 243 mg

Cystine 250 mg

Phenylalanine 1858 mg

Tyrosine 538 mg

Valine 937 mg

Arginine 1299 mg

Histidine 774 mg

Alanine 972 mg

Aspartic acid 2146 mg

Glutamic acid 5031 mg

Glycine 802 mg

Proline 955 mg

Serine 1028 mg

Hydroxyproline 0 mg

Vitamins Quantity%DV† Thiamine (B1) 54%0.643 mg

Riboflavin (B2) 14%0.187 mg

Niacin (B3) 19%2.965 mg

Pantothenic acid (B5) 25%1.266 mg

Vitamin B6 17%0.283 mg

Folate (B9) 114%456 μg

Choline 0%0.000000 mg
Vitamin C 0%0 mg

Vitamin E 0%0.000000 mg

Vitamin K 0%0.000000 μg

Minerals Quantity%DV†
Calcium 10%130 mg

Iron 29%5.23 mg
Magnesium 44%183 mg

Manganese 78%1.791 mg

Phosphorus 29%367 mg

Potassium 46%1392 mg
Sodium 1%17 mg

Zinc 25%2.76 mg

Link to USDA Database entry

Values for Choline, Vit. E/K unavailable

†Percentages estimated using US recommendations for adults.[62]

Pigeon peas contain high levels of protein and the important amino acids methionine, lysine, and tryptophan.[63]

The following table indicates completeness of nutritional profile of various amino acids within mature seeds of pigeon pea.

Essential Amino Acid	Available mg/g of Protein	Min. Required mg/g of Protein
Tryptophan	9.76	7

Threonine	32.34	27
Isoleucine	36.17	25
Leucine	71.3	55
Lysine	70.09	51
Methionine+Cystine	22.7	25
Phenylalanine+Tyrosine	110.4	47
Valine	43.1	32
Histidine	35.66	18

Methionine + Cystine combination is the only limiting amino acid combination in pigeon pea. In contrast to the mature seeds, the immature seeds are generally lower in all nutritional values, however they contain a significant amount of vitamin C (39 mg per 100 g serving) and have a slightly higher fat content. Research has shown that the protein content of the immature seeds is of a higher quality.[64]

Nutrient contents in %DV of common foods (raw, uncooked) per 100 g Cultivation

Harvested pigeon peas from Cape Verde

Pigeon peas can be of a perennial variety, in which the crop can last three to five years (although the seed yield drops considerably after the first two years), or an annual variety more suitable for seed production.[69]

Global production

Naturalized pigeon peas growing on Cha das Caldeiras on Fogo island in Cape Verde

World production of pigeon peas is estimated at 4.49 million tons.[70] About 63% of this production comes from India.[71] The total number of hectares grown to pigeon pea is estimated at 5.4 million.[70] India accounts for 72% of the area grown to pigeon pea or 3.9 million hectares. Africa is the secondary centre of diversity and at present it contributes about 21% of global production with 1.05 million tons. Malawi, Tanzania, Kenya, Mozambique and Uganda are the major producers in Africa.[72]

The pigeon pea is an important legume crop of rainfed agriculture in the semiarid tropics. The Indian subcontinent, Africa and Central America, in that order, are the world's three main pigeon pea-producing regions. Pigeon peas are cultivated in more than 25 tropical and subtropical countries, either as a sole crop or intermixed with cereals, such as sorghum (Sorghum bicolor), pearl millet (Pennisetum glaucum), or maize (Zea mays), or with other legumes, such as peanuts (Arachis hypogea). Being a legume capable of symbiosis with Rhizobia, the bacteria associated with the pigeon pea enrich soils through symbiotic nitrogen fixation.[73]

The crop is cultivated on marginal land by resource-poor farmers, who commonly grow traditional medium- and long-duration (5–11 months) landraces. Short-duration pigeon peas (3–4 months) suitable for multiple cropping have recently been developed. Traditionally, the use of such input as fertilizers, weeding, irrigation, and pesticides is minimal, so present yield levels are low (average = 700 kilograms per hectare (620 lb/acre)). Greater attention is now being given to managing the crop because it is in high demand at remunerative prices.

Pigeon peas are very drought-resistant and can be grown in areas with less than 650 mm annual rainfall. With the maize crop failing three out of five years in drought-prone areas of Kenya, a consortium led by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) aimed to promote the pigeon pea as a drought-resistant, nutritious alternative crop.[74]

Breeding

John Spence, a botanist and politician from Trinidad and Tobago, developed several varieties of dwarf pigeon peas which can be harvested by machine, instead of by hand.[75]

Genome sequence

The pigeon pea is the first seed legume plant to have its complete genome sequenced. The sequencing was first accomplished by a group of 31 Indian scientists from the Indian Council of Agricultural Research. It was then followed by a global research partnership, the International Initiative for Pigeon pea Genomics (IIPG), led by ICRISAT with partners such as BGI–Shenzhen (China), US research laboratories like University of Georgia, University of California-Davis, Cold Spring Harbor Laboratory, and National Centre for Genome Resources, European research institutes like the National University of Ireland Galway. It also received support from the CGIAR Generation Challenge Program, US National Science Foundation and in-kind contribution from the collaborating research institutes.[76][77] It is the first time that a CGIAR-supported research center such as ICRISAT led the genome sequencing of a food crop. There was a controversy over this as CGIAR did not partner with a national team of scientists and broke away from the Indo American Knowledge Initiative to start their own sequencing in parallel.[78] The 616 mature microRNAs and 3919 long non-codingRNAs sequences were identified in the genome of pigeon pea.[79]

Dehulling

Kenyans shelling pigeon peas

Various methodologies exist in order to remove the pulse from its shell. In earlier days hand pounding was common. Several traditional methods are used that can be broadly classified under two categories: the wet method and the dry method. The Wet method Involves water soaking, sun drying and dehulling. The Dry method Involves oil/water application, drying in the sun, and dehulling. Depending on the magnitude of operation, large-scale commercial dehulling of large quantities of pigeon pea into its deskinned, split version, known as toor dal in Hindi, is done in mechanically operated mills.[80][81]

Uses

In cuisine

Pigeon peas are both a food crop (dried peas, flour, or green vegetable peas) and a forage/cover crop. In combination with cereals, pigeon peas make a well-balanced meal and hence are favored by nutritionists as an essential ingredient for balanced diets. The dried peas may be sprouted briefly, then cooked, for a flavor different from the green or dried peas. Sprouting also enhances the digestibility of dried pigeon peas via the reduction of indigestible sugars that would otherwise remain in the cooked dried peas.[82]

Africa

A bowl of Cape Verdean fixon Kongu

In Cape Verde they make a soup with the dried pigeon peas called feijão Congo, after its own name, made with dried pigeon peas in a similar manner to Brazilian feijoada.[83]

In Kenya and throughout the Swahili-speaking region of East Africa, pigeon peas are utilized in dishes such as mbaazi na mahamri, that is usually served for breakfast.[84][85]

In the Enugu state of Nigeria, and igbo dish called Ẹchịcha or Achịcha is made with palm oil, cocoyam, and seasoning.[86] It is also similar to other dishes from the state such as ayarya ji and fiofio.[87][88][89]

In Ethiopia, the pods, the young shoots and leaves, are cooked and eaten.[90]

Asia

Dal/pappu and rice, the twice-daily staple meal for most people in India and the Indian subcontinent

In India, it is one of the most popular pulses, being an important source of protein in a mostly vegetarian diet. It is the primary accompaniment to rice or roti and has the status of staple food throughout the length and breadth of India. In regions where it grows, fresh young pods are eaten as a vegetable in dishes such as sambar.

In the Western Visayas region of the Philippines, pigeon peas are the main ingredient of a very popular dish called "KBL" - an acronym for "Kadyos" (pigeon pea), "Baboy" (pork), and "Langka" (jackfruit). It is a savory soup with rich flavors coming from the pigeon peas, smoked pork preferably the legs or tail, and souring agent called batuan. Raw jackfruit meat is chopped and boiled to soft consistency, and serves as an extender. The violet color of the soup comes from the pigment of the variety commonly grown in the region.[91]

The Americas

In the Caribbean coast of Colombia, such as the Atlántico department of Colombia, the sopa de guandú con carne salada (or simply "gandules") is made with pigeon peas, yam, plantain, yuca, and spices.[92] During the week of Semana santa a sweet is made out of pigeon peas called dulce de guandules which is made by mashed and sweetened pigeon peas with origins in the maroon community of San Basilio de Palenque.[93][94][95]

In the Dominican Republic, a dish made of rice and green pigeon peas called moro de guandules is a traditional holiday food. It is also consumed as guandules guisados, which is a savoury stew with coconut and squash served with white rice. A variety of sancocho is also made based on green pigeon peas that includes poultry, pork, beef, yams, yucca, squash, plantain and others. Dominicans have a high regard for this legume and it is consumed widely. [96]

In Panama, pigeon peas are used in a dish called Arroz con guandú y coco or "rice with pigeon peas and coconut" traditionally prepared and consumed during the end of year holidays.[97]

In Puerto Rico, arroz con gandules is made with rice and pigeon peas and sofrito which is a traditional dish, especially during Christmas season.[98] Pigeon peas can also be made in to a stew called asopao de gandules, with plantain balls.[99]

Jamaica also uses pigeon peas instead of kidney beans in their rice and peas dish, especially during the Christmas season.[100]

Trinidad and Tobago and Grenada have their own variant, called pelau, which includes either beef or chicken, and occasionally pumpkin and pieces of cured pig tail.[101]

Unlike in some other parts of the Greater Caribbean, in The Bahamas pigeon peas are used in dried form, light brown in color to make the heartier, heavier, signature Bahamian staple dish "Peas 'n Rice."[102]

Oceania

In Hawaii they are used to make a dish called gandule rice,[103] also called godule rice,[104] gundule rice,[105] and ganduddy rice[106] originates on the island from the Puerto Rican community with historic ties to the island and is prepared in a similar manner to that of traditional Puerto Rican arroz con gandules.[107]

Other uses

Agricultural

Harvested pods of pigeon peas in Benin.

It is an important ingredient of animal feed used in West Africa, especially in Nigeria, where it is also grown. Leaves, pods, seeds and the residues of seed processing are used to feed all kinds of livestock.[108]

In the Congo pigeon peas are utilized as one of the main food forest and soil improvement crops after using a slash-and-burn fire technique called maala.[109]

Pigeon peas are in some areas an important crop for green manure, providing up to 90 kg nitrogen per hectare.[110] The woody stems of pigeon peas can also be used as firewood, fencing, thatch and as a source for rope fiber.[111]

Medicinal

In the Republic of Congo the Kongo, Lari, and Dondo people use the sap of the leaves as an eyedrop for epilepsy.[112]

In Madagascar the branches have been used as a teeth cleaning twig a arachidis

Chickpea

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Chickpeas

The two main types of chickpea: the larger light tan kabuli and variously coloured desi chickpea. They are green when picked early and vary through tan or beige, speckled, dark brown to black. 75% of world production is of the smaller desi type.

Dried chickpeas. The larger light tan kabuli and variously coloured desi are the two main types of chickpea. They are green when picked early and vary through tan or beige, speckled, dark brown to black. 75% of world production is of the smaller desi type.

Sprouted chickpea

Sprouted chickpea

Scientific classificationEdit this classification

Kingdom: Plantae

Clade: Tracheophytes

Clade: Angiosperms

Clade: Eudicots

Clade: Rosids

Order: Fabales

Family: Fabaceae

Subfamily: Faboideae

Genus: Cicer

Species: C. arietinum

Binomial name Cicer

arietinum

L.

Synonyms[1]

Cicer album hort.

Cicer arientinium L. [Spelling variant]

Cicer arientinum L. [Spelling variant]

Cicer edessanum Bornm.

Cicer grossum Salisb.

Cicer nigrum hort.

Cicer physodes Rchb.

Cicer rotundum Alef.

Cicer sativum Schkuhr

Cicer sintenisii Bornm.

Ononis crotalarioides M.E.Jones

Cicer arietinum noir – MHNT

The chickpea or chick pea (Cicer arietinum) is an annual legume of the family Fabaceae, subfamily Faboideae.[2][3] Its different types are variously known as gram[4][5] or Bengal gram,[5] chhana, chana, or channa, garbanzo[5] or garbanzo bean, or Egyptian pea.[4] Chickpea seeds are high in protein. It is one of the earliest cultivated legumes, the oldest archaeological evidence of which was found in Syria.[6][7][8]

The chickpea is a key ingredient in Mediterranean and Middle Eastern cuisines, used in hummus, and, when soaked and coarsely ground with herbs and spices then made into patties and fried, falafel. As an important part of Indian cuisine, it is used in salads, soups and stews, and curry, in chana masala, and in other food products that contain channa (chickpeas). In 2019, India was responsible for 70% of global chickpea production.[9]

Etymology

The name "chickpea", earlier "chiche pease", is modelled on Middle French pois chiche, where chiche comes from Latin cicer. "Chich" was used by itself in English from the 14th to the 18th centuries.[10] The word garbanzo, from an alteration of Old Spanish arvanço, came first to English as "garvance" in the 17th century, being gradually anglicized to "calavance", though that came to refer to a variety of other beans, including the hyacinth bean. The current form garbanzo comes directly from modern Spanish.[11]

History

The earliest well-preserved archaeobotanical evidence of chickpea outside its wild progenitor's natural distribution area comes from the site of Tell el-Kerkh, in modern Syria, dating back to the early PrePottery Neolithic period around c.8400 BC.[12]

Cicer reticulatum is the wild progenitor of chickpeas. This species currently grows only in southeast Turkey, where it is believed to have been domesticated. The domestication event can be dated to around 7000 BC. Domesticated chickpeas have been found at Pre-Pottery Neolithic B sites in Turkey and the Levant, namely at Çayönü, Hacilar, and Tell es-Sultan (Jericho).[13] Chickpeas then spread to the Mediterranean region around 6000 BC and India around 3000 BC.[13]

In southern France, mesolithic layers in a cave at L'Abeurador, Hérault, have yielded chickpeas, carbondated to 6790±90 BC.[14] They were found in the late Neolithic (about 3500 BC) sites at Thessaly, Kastanas, Lerna and Dimini, Greece.

Chickpeas are mentioned in Charlemagne's Capitulare de villis (about 800 AD) as cicer italicum, as grown in each imperial demesne. Albertus Magnus mentions red, white, and black varieties. The 17th-century botanist Nicholas Culpeper noted "chick-pease or cicers" are less "windy" than peas and more nourishing. Ancient people also associated chickpeas with Venus because they were said to offer medical uses such as increasing semen and milk production, inducing menstruation and urination, and helping to treat kidney stones.[15] "White cicers" were thought to be especially strong and helpful.[15]

In 1793, ground, roasted chickpeas were noted by a German writer as a substitute for coffee in Europe.[16] In the First World War, they were grown for this use in some areas of Germany.[17] They are still sometimes brewed instead of coffee.[16]

Genome sequencing

Sequencing of the genome of the chickpea has been completed for 90 chickpea genotypes, including several wild species.[18] A collaboration of 20 research organizations, led by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), sequenced CDC Frontier, a kabuli chickpea variety, and identified more than 28,000 genes and several million genetic markers.[19]

Description

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Flowering and fruiting chickpea plant

Chickpea pods

Flower of Chickpea

Pollen grains of Chickpea

The plant grows to 20–50 cm (8–20 in) high and has small, feathery leaves on either side of the stem. Chickpeas are a type of pulse, with one seedpod containing two or three peas. It has white flowers with blue, violet, or pink veins.

Dozens of varieties of chickpea are cultivated throughout the world. In general, American and Iranian chickpeas are sweeter than Indian chickpeas. Kermanshah chickpeas in sizes 8 and 9 are considered among the world's highest quality.[20]

Varieties

The most common variety of chickpea in South Asia, Ethiopia, Mexico, and Iran is the desi type, also called Bengal gram.[21] It has small, dark seeds and a rough coat. It can be black, green or speckled. In Hindi, it is called desi chana 'native chickpea' or kala chana 'black chickpea', and in Assamese, it is called boot or chholaa boot. It can be hulled and split to make chana dal, Kurukshetra Prasadam (channa laddu),[22] and bootor daali.

Around the Mediterranean and in the Middle East, the most common variety of chickpea is the kabuli type. It is large and tan-colored, with a smooth coat. It was introduced to India in the 18th century from Afghanistan and is called kabuli chana in Hindi.[23]

An uncommon black chickpea, ceci neri, is grown only in Apulia and Basilicata, in southern Italy. It is around the same size as garbanzo beans, larger and darker than the 'desi' variety.

Production

Production of chickpeas – 2020

Country Production

(millions of tonnes)

India

11.1

Turkey

0.6

Myanmar

0.5

Pakistan

0.5

World

15.1

Source: FAOSTAT of the United Nations[9]

In 2020, world production of chickpeas was 15 million tonnes, led by India with 73% of the global total,[24] and Turkey, Myanmar, and Pakistan as secondary producers (table).[9]

Uses

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Culinary

See also: List of chickpea dishes

Chana dal, split Bengal gram

Hummus with olive oil

Khaman, steamed chickpea flour snack

Chickpeas are usually rapidly boiled for 10 minutes and then simmered for longer. Dried chickpeas need a long cooking time (1–2 hours) but will easily fall apart when cooked longer. If soaked for 12–24 hours before use, cooking time can be shortened by around 30 minutes. Chickpeas can also be pressure cooked or sous vide cooked at 90 °C (194 °F).

Mature chickpeas can be cooked and eaten cold in salads, cooked in stews, ground into flour, ground and shaped in balls and fried as falafel, made into a batter and baked to make farinata or socca, or fried to make panelle. Chickpea flour is known as gram flour or besan in South Asia and is used frequently in South Asian cuisine.

In Portugal, chickpeas are one of the main ingredients in rancho, eaten with pasta, meat, or rice. They are used in other hot dishes with bacalhau and in soups, meat stews, salads mixed with tuna and vegetables, olive oil, vinegar, hot pepper and salt. In Spain, they are used cold in tapas and salads, as well as in cocido madrileño.

Hummus is the Arabic word for chickpeas, which are often cooked and ground into a paste and mixed with tahini (sesame seed paste) to make ḥummuṣ bi ṭaḥīna, usually called simply hummus in English. By the end of the 20th century, hummus had become common in American cuisine:[25] by 2010, 5% of Americans consumed it regularly,[25] and it was present at some point in 17% of American households.[26]

In the Middle East, chickpeas are also roasted, spiced, and eaten as a snack, such as leblebi.

Chickpeas and Bengal grams are used to make curries.[27] They are one of the most popular vegetarian foods in the Indian subcontinent[28] and in diaspora communities of many other countries, served with a variety of bread or steamed rice. Popular dishes in Indian cuisine are made with chickpea flour, such as mirchi bajji and mirapakaya bajji.[29] In India, as well as in the Levant, unripe chickpeas are often picked out of the pod and eaten as a raw snack, and the leaves are eaten as a leaf vegetable in salads. In India, desserts such as besan halwa[30] and sweets such as mysore pak,[31] besan barfi[32] and laddu[33] are made.

Chickpea flour is used to make "Burmese tofu", which was first known among the Shan people of Burma. In South Asian cuisine, chickpea flour (besan) is used as a batter to coat vegetables before deep frying to make pakoras. The flour is also used as a batter to coat vegetables and meats before frying or fried alone, such as panelle (little bread), a chickpea fritter from Sicily. Chickpea flour is used to make the

Mediterranean flatbread socca and is called panisse in Provence, southern France. It is made of cooked chickpea flour, poured into saucers, allowed to set, cut into strips, and fried in olive oil, often eaten during Lent. In Tuscany, chickpea flour (farina di ceci) is used to make an oven-baked pancake: the flour is mixed with water, oil and salt. Chickpea flour, known as kadlehittu in Kannada, is used for making sweet dish Mysore pak.

In the Philippines, chickpeas preserved in syrup are eaten as sweets and in desserts such as halo-halo.

Ashkenazi Jews traditionally serve whole chickpeas, referred to as arbes (אַרבעס) in Yiddish, at the Shalom Zachar celebration for baby boys. The chickpeas are boiled until soft and served hot with salt and lots of ground black pepper.[34]

Guasanas or garbanza is a Mexican chickpea street snack. The beans, while still green, are cooked in water and salt, kept in a steamer to maintain their humidity, and served in a plastic bag.

A chickpea-derived liquid (aquafaba) can be used as an egg white replacement to make meringue[35] or ice cream, with the residual pomace used as flour.[36]

Doubles, a street food in Trinidad and Tobago Doubles,
a street food in Trinidad and Tobago

Manchego cuisine; chickpea and Silene vulgaris stew (potaje de garbanzos y collejas) Manchego
cuisine; chickpea and Silene vulgaris stew (potaje de garbanzos y collejas)

Farinata di ceci, a traditional Italian chickpea snack food Farinata
di ceci, a traditional Italian chickpea snack food

Chakhchoukha in Algerian cuisine; freshly cooked marqa before mixing with rougag
Chakhchoukha in Algerian cuisine; freshly cooked marqa before mixing with rougag

Chana masala, India Chana

masala, India

Halua chickpeas, Bangladesh Halua

chickpeas, Bangladesh

Fried chickpea

Fried chickpea

Animal feed

Chickpeas are an energy and protein source as animal feed.[37]

Raw chickpeas have a lower trypsin and chymotrypsin inhibitor content than peas, common beans, and soybeans. This leads to higher nutrition values and fewer digestive problems in nonruminants. Nonruminant diets can be completed with 200 g/kg of raw chickpeas to promote egg production and growth of birds and pigs. Higher amounts can be used when chickpeas are treated with heat.[37]

Experiments have shown that ruminants grow equally well and produce an equal amount and quality of milk when soybean or cereal meals are replaced with chickpeas. Pigs show the same performance, but growing pigs experience a negative effect of raw chickpea feed; extruded chickpeas can increase performance even in growing pigs. Only young broilers (starting period) showed worse performance in poultry diet experiments with untreated chickpeas. Fish performed equally well when extruded chickpeas replaced their soybean or cereal diet.[37] Chickpea seeds have also been used in rabbit diets.[21]

Secondary components of legumes—such as lecithin, polyphenols, oligosaccharides; and amylase, protease, trypsin and chymotrypsin inhibitors—can lead to lower nutrient availability, and thus to impaired growth and health of animals (especially in nonruminants). Ruminants generally have less trouble digesting legumes with secondary components since they can inactivate them in the rumen liquor. Their diets can be supplemented by 300 g/kg or more raw chickpea seeds.[37] However, protein digestibility and energy availability can be improved through treatments such as germination, dehulling, and heat. Extrusion is a very good heat technique to destroy secondary legume components since the proteins are irreversibly denatured. Overprocessing may decrease the nutritional value; extrusion leads to losses in minerals and vitamins, while dry heating does not change the chemical composition.[37]
Nutrition

Chickpeas, mature seeds, cooked, no salt

Nutritional value per 100 g (3.5 oz)

Energy 686 kJ (164 kcal)

Carbohydrates

27.42 g

Sugars 4.8 g
Dietary fibre 7.6 g

Fat

2.59 g

Saturated 0.27 g

Monounsaturated 0.58 g

Polyunsaturated 1.16 g

Protein

8.86 g

Vitamins Quantity%DV†

Vitamin A equiv. 0%1 µg

Thiamine (B1) 10%0.12 mg

Riboflavin (B2) 5%0.06 mg

Niacin (B3) 3%0.53 mg

Pantothenic acid (B5) 6%0.29 mg
Vitamin B6 8%0.14 mg

Folate (B9) 43%172 µg

Vitamin C 1%1.3 mg

Vitamin E 2%0.35 mg

Vitamin K 3%4 µg

Minerals Quantity%DV†

Calcium 4%49 mg

Iron 16%2.89 mg

Magnesium 11%48 mg

Manganese 45%1.03 mg

Phosphorus 13%168 mg

Potassium 10%291 mg
Sodium 0%7 mg

Zinc 14%1.53 mg

Other constituents Quantity

Water 60.21 g

Link to USDA Database entry

†Percentages estimated using US recommendations for adults.[38]

Chickpeas, dried seeds, raw

Nutritional value per 100 g (3.5 oz)

Energy 1,581 kJ (378 kcal)

Carbohydrates

62.95 g

Sugars 10.7 g

Dietary fibre 12.2 g

Fat

6.04 g

Saturated 0.603

Monounsaturated 1.377

Polyunsaturated 2.731

Protein

20.5 g

Vitamins Quantity%DV†

Vitamin A equiv. 0%3 μg

Thiamine (B1) 40%0.477 mg

Riboflavin (B2) 16%0.212 mg

Niacin (B3) 10%1.541 mg

Pantothenic acid (B5) 32%1.588 mg
Vitamin B6 31%0.535 mg

Folate (B9)	139%557 µg
Vitamin C	4%4 mg
Vitamin E	5%0.82 mg
Vitamin K	8%9 µg
Minerals	Quantity%DV†
Calcium	4%57 mg
Copper	73%0.656 mg
Iron	24%4.31 mg
Magnesium	19%79 mg
Phosphorus	20%252 mg
Potassium	24%718 mg
Sodium	1%24 mg
Zinc	25%2.76 mg
Other constituents	Quantity
Water	7.68 g

Link to USDA Database entry

†Percentages estimated using US recommendations for adults.[38]

Chickpeas are a nutrient-dense food, providing rich content (20% or higher of the Daily Value, DV) of protein, dietary fiber, folate, and certain dietary minerals, such as iron and phosphorus in a 100-gram reference amount (see adjacent nutrition table). Thiamin, vitamin B6, magnesium, and zinc contents are moderate, providing 10–16% of the DV. Compared to reference levels established by the United Nations Food and Agriculture Organization and World Health Organization, proteins in cooked and germinated chickpeas are rich in essential amino acids such as lysine, isoleucine, tryptophan, and total aromatic amino acids.[39]

A 100-gram (3+1⁄2-ounce) reference serving of cooked chickpeas provides 686 kilojoules (164 kilocalories) of food energy. Cooked chickpeas are 60% water, 27% carbohydrates, 9% protein and 3% fat (table).[37] 75% of the fat content is unsaturated fatty acids for which linoleic acid comprises 43% of the total fat.[40]

Effects of cooking

Cooking treatments do not lead to variance in total protein and carbohydrate content.[41][42] Soaking and cooking of dry seeds possibly induces chemical modification of protein-fibre complexes, which leads to an increase in crude fibre content. Thus, cooking can increase protein quality by inactivating or destroying heat-labile antinutritional factors.[41] Cooking also increases protein digestibility, essential amino acid index, and protein efficiency ratio. Although cooking lowers concentrations of amino acids such as tryptophan, lysine, total aromatic, and sulphur-containing amino acids, their contents are still higher than proposed by the FAO/WHO reference.[41] Raffinose and sucrose and other reducing sugars diffuse from the chickpea into the cooking water and this reduces or completely removes these components from the chickpea. Cooking also significantly reduces fat and mineral content. The B vitamins riboflavin, thiamin, niacin, and pyridoxine dissolve into cooking water at differing rates.[41]

Germination

Germination of chickpeas improves protein digestibility, although at a lower level than cooking. Germination degrades proteins to simple peptides, improving crude protein, nonprotein nitrogen, and crude fibre content. Germination decreases lysine, tryptophan, sulphur and total aromatic amino acids, but most contents are still higher than proposed by the FAO/WHO reference pattern.[41]

Oligosaccharides, such as stachyose and raffinose, are reduced in higher amounts during germination than during cooking. Minerals and B vitamins are retained more effectively during germination than with cooking. Phytic acids are reduced significantly, but trypsin inhibitor, tannin, and saponin reduction is less effective than cooking.[41]

Autoclaving, microwave cooking, boiling

All treatments of cooking improve protein digestibility.[citation needed] Essential amino acids are slightly increased by boiling and microwave cooking compared to autoclaving and germination. Overall, microwave cooking leads to a significantly lower loss of nutrients than autoclaving and boiling.[citation needed][disputed – discuss]

Finally, all treatments improve protein digestibility, protein efficiency ratio, and essential amino acid index. Microwave cooking seems to be an effective method to prepare chickpeas because of its improved nutritional value and lower cooking time.[41]

Leaves

In some parts of the world, young chickpea leaves are consumed as cooked green vegetables. Especially in malnourished populations, it can supplement important dietary nutrients because regions where chickpeas are consumed have sometimes been found to have populations lacking micronutrients.[43] Chickpea leaves have a significantly higher mineral content than either cabbage leaves or spinach leaves.[43] Environmental factors and nutrient availability could influence mineral concentrations in natural settings. Consumption of chickpea leaves may contribute nutrients to the diet.[43]

Research

The consumption of chickpeas is under preliminary research for the potential to improve nutrition and affect chronic diseases.[42][44]

Heat and nutrient cultivation

Agricultural yield for chickpeas is often based on genetic and phenotypic variability, which has recently been influenced by artificial selection.[45] The uptake of macronutrients such as inorganic phosphorus or nitrogen is vital to the plant development of Cicer arietinum, commonly known as the perennial chickpea.[46] Heat cultivation and macronutrient coupling are two relatively unknown methods used to increase the yield and size of the chickpea. Recent research has indicated that a combination of heat treatment along with the two vital macronutrients, phosphorus and nitrogen, are the most critical components to increasing the overall yield of Cicer arietinum.[46]

Perennial chickpeas are a fundamental source of nutrition in animal feed as they are high-energy and protein sources for livestock. Unlike other food crops, the perennial chickpea can change its nutritional content in response to heat cultivation. Treating the chickpea with a constant heat source increases its protein content almost threefold.[46] Consequently, the impact of heat cultivation affects the protein content of the chickpea itself and the ecosystem it supports. Increasing the height and size of chickpea plants involves using macronutrient fertilization with varying doses of inorganic phosphorus and nitrogen.[47]

The level of phosphorus that a chickpea seed is exposed to during its lifecycle has a positive correlation relative to the height of the plant at full maturity.[47] Increasing the levels of inorganic phosphorus at all doses incrementally increases the height of the chickpea plant. Thus, the seasonal changes in phosphorus soil content, as well as periods of drought that are known to be a native characteristic of the dry Middle-Eastern region where the chickpea is most commonly cultivated, have a strong effect on the growth of the plant itself. Plant yield is also affected by a combination of phosphorus nutrition and water supply, resulting in a 12% increase in crop yield.[47]

Nitrogen nutrition is another factor that affects the yield of Cicer arietinum, although the application differs from other perennial crops regarding the levels administered on the plant. High doses of nitrogen inhibit the yield of the chickpea plant.[48] Drought stress is a likely factor that inhibits nitrogen uptake and subsequent fixation in the roots of Cicer arietinum. The perennial chickpea's growth depends on the balance between nitrogen fixation and assimilation, which is also characteristic of many other agricultural plant types. The influence of drought stress, sowing date, and mineral nitrogen supply affect the plant's yield and size, with trials showing that Cicer arietinum differed from other plant species in its capacity to assimilate mineral nitrogen supply from the soil during drought stress.[48] Additional minerals and micronutrients make the absorption process of nitrogen and phosphorus more available. Inorganic phosphate ions are generally attracted towards charged minerals such as iron and aluminium oxides.[49]

Additionally, growth and yield are also limited by the micronutrients zinc and boron deficiencies in the soil. Boron-rich soil increased chickpea yield and size, while soil fertilization with zinc seemed to have no apparent effect on the chickpea yield.[50]

Pathogens

Pathogens in chickpeas are the main cause of yield loss (up to 90%).[citation needed] One example is the fungus Fusarium oxysporum f.sp. ciceris, present in most of the major pulse crop-growing areas and causing regular yield damages between 10 and 15%.[51] Many plant hosts produce heat shock protein 70s including C. arietinum.[52] In response to F. o. ciceris Gupta et al., 2017 finds C. arietinum produces an orthologue of AtHSP70-1, an Arabidopsis HSP70.[52]

From 1978 until 1995, the worldwide number of pathogens increased from 49 to 172, of which 35 were recorded in India. These pathogens originate from groups of bacteria, fungi, viruses, mycoplasma and nematodes and show a high genotypic variation. The most widely distributed pathogens are Ascochyta rabiei (35 countries), Fusarium oxysporum f.sp. ciceris (32 countries) Uromyces ciceris-arietini (25 countries), bean leafroll virus (23 countries), and Macrophomina phaseolina (21 countries).[53] Ascochyta disease emergence is favoured by wet weather; spores are carried to new plants by wind and water splash.[54]

The stagnation of yield improvement over the last decades is linked to the susceptibility to pathogens.[55] Research for yield improvement, such as an attempt to increase yield from 0.8 to 2.0 metric tons per hectare (0.32 to 0.80 long ton/acre; 0.36 to 0.89 short ton/acre) by breeding coldresistant varieties, is always linked with pathogen-resistance breeding as pathogens such as Ascochyta rabiei and F. o. f.sp. ciceris flourish in conditions such as cold temperature. Research started selecting favourable genes for pathogen resistance and other traits through marker-assisted selection. This method is a promising sign for the fu

Barley

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Barley

Scientific classificationEdit this classification

Kingdom: Plantae

Clade: Tracheophytes

Clade: Angiosperms Clade:

Monocots

Clade: Commelinids

Order: Poales

Family: Poaceae

Subfamily: Pooideae

Genus: Hordeum

Species: H. vulgare

Binomial name

Hordeum vulgare

L.[1]

Synonyms[2]

List

Barley (Hordeum vulgare), a member of the grass family, is a major cereal grain grown in temperate climates globally. It was one of the first cultivated grains; it was domesticated in the Fertile Crescent around 9000 BC, giving it nonshattering spikelets and making it much easier to harvest. Its use then spread throughout Eurasia by 2000 BC. Barley prefers relatively low temperatures to grow, and welldrained soil. It is relatively tolerant of drought and soil salinity, but is less winter-hardy than wheat or rye.

In 2022, barley was fourth among grains in quantity produced, 155 million tonnes, behind maize, wheat, and rice. Globally 70% of barley production is used as animal feed, while 30% is used as a source of fermentable material for beer, or further distilled into whisky, and as a component of various foods. It is used in soups and stews, and in barley bread of various cultures. Barley grains are commonly made into malt in a traditional and ancient method of preparation. In English folklore, John Barleycorn personifies the grain, and the alcoholic beverages made from it. English pub names such as The Barley Mow allude to barley's role in the production of beer.

Etymology

The Barley Barn at Cressing, Essex, built around 1220; its name means "barley-store".[3]

The Old English word for barley was bere.[4] This survives in the north of Scotland as bere; it is used for a strain of six-row barley grown there.[5] Modern English barley derives from the Old English adjective bærlic, meaning "of barley".[3][6] The word barn derives from Old English bere-aern meaning "barleystore".[3] The name of the genus is from Latin hordeum, barley, likely related to Latin horrere, to bristle.[7]

Description

Botanical illustration of leafy stem with roots, flowers, and 2- and 6-row ears

Barley is a cereal, a member of the grass family with edible grains. Its flowers are clusters of spikelets arranged in a distinctive herringbone pattern. Each spikelet has a long thin awn (to 160 mm (6.3 in) long), making the ears look tufted. The spikelets are in clusters of three. In six-row barley, all three spikelets in each cluster are fertile; in two-row barley, only the central one is fertile.[8] It is a self-pollinating, diploid species with 14 chromosomes.[9]

The genome of barley was sequenced in 2012 by the International Barley Genome Sequencing Consortium and the UK Barley Sequencing Consortium.[10] The genome is organised into seven pairs[11] of nuclear chromosomes (recommended designations: 1H, 2H, 3H, 4H, 5H, 6H and 7H), and one mitochondrial and one chloroplast chromosome, with a total of 5000 Mbp.[12] Details of the genome are freely available in several barley databases.[13]

Origin

External phylogeny

The barley genus Hordeum is relatively closely related to wheat and rye within the Triticeae, and more distantly to rice within the BOP clade of grasses (Poaceae).[14] The phylogeny of the Triticeae is complicated by horizontal gene transfer between species, so there is a network of relationships rather than a simple inheritance-based tree.[15]

(Part of Poaceae)

BOP clade

Bambusoideae (bamboos)

Pooideae

other grasses

(fescue, ryegrass)

Triticeae

Hordeum (barley)

Triticum (wheat)

Secale (rye)

Oryza (rice)

PACMAD clade

other grasses

Sorghum (sorghum)

Zea (maize)

Domestication

Genetic analysis on the spread of barley from 9,000 to 2,000 BCE[16]

Barley was one of the first grains to be domesticated in the Fertile Crescent, an area of relatively abundant water in Western Asia,[17] around 9,000 BC.[16][18] Wild barley (H. vulgare ssp. spontaneum) ranges from North Africa and Crete in the west to Tibet in the east.[9] A study of genome-wide diversity markers found Tibet to be an additional center of domestication of cultivated barley.[19] The earliest archaeological evidence of the consumption of wild barley, Hordeum spontaneum, comes from the Epipaleolithic at Ohalo II at the southern end of the Sea of Galilee, where grinding stones with traces of starch were found. The remains were dated to about 23,000 BC.[9][20][21] The earliest evidence for the domestication of barley, in the form of cultivars that cannot reproduce without human assistance, comes from Mesopotamia, specifically the Jarmo region of modern-day Iraq, around 9,000-7,000 BC.[22][23]

Domestication changed the morphology of the barley grain substantially, from an elongated shape to a more rounded spherical one.[24] Wild barley has distinctive genes, alleles, and regulators with potential for resistance to abiotic or biotic stresses; these may help cultivated barley to adapt to climatic changes.[25] Wild barley has a brittle spike; upon maturity, the spikelets separate, facilitating seed dispersal. Domesticated barley has nonshattering spikelets, making it much easier to harvest the mature ears.[9] The nonshattering condition is caused by a mutation in one of two tightly linked genes known as Bt1 and Bt2; many cultivars possess both mutations. The nonshattering condition is recessive, so varieties of barley that exhibit this condition are homozygous for the mutant allele.[9] Domestication in barley is followed by the change of key phenotypic traits at the genetic level.[26]

The wild barley found currently in the Fertile Crescent may not be the progenitor of the barley cultivated in Eritrea and Ethiopia, indicating that it may have been domesticated separately in eastern Africa.[27]

Spread

Further information: Neolithic revolution

An account of barley rations issued monthly to adults (30 or 40 pints) and children (20 pints) written in cuneiform on clay tablet in year 4 of King Urukagina (circa 2350 BCE), from Girsu, Iraq

Archaeobotanical evidence shows that barley had spread throughout Eurasia by 2,000 BC.[16] Genetic analysis demonstrates that cultivated barley followed several different routes over time.[16] By 4200 BC domesticated barley had reached Eastern Finland.[28] Barley has been grown in the Korean Peninsula since the Early Mumun Pottery Period (circa 1500–850 BC).[29] Barley (Yava in Sanskrit) is mentioned many times in the Rigveda and other Indian scriptures as a principal grain in ancient India.[30] Traces of barley cultivation have been found in post-Neolithic Bronze Age Harappan civilization 5,700–3,300 years ago.[31] Barley beer was probably one of the first alcoholic drinks developed by Neolithic humans;[32] later it was used as currency.[32] The Sumerian language had a word for barley, akiti. In ancient Mesopotamia, a stalk of barley was the primary symbol of the goddess Shala.[33]

Barley in Egyptian hieroglyphs

jt barley determinative/ideogram M34

jt (common) spelling

i t U9

M33 šma

determinative/ideogram

U9

Rations of barley for workers appear in Linear B tablets in Mycenaean contexts at Knossos and at Mycenaean Pylos.[34] In mainland Greece, the ritual significance of barley possibly dates back to the earliest stages of the Eleusinian Mysteries. The preparatory kykeon or mixed drink of the initiates, prepared from barley and herbs, mentioned in the Homeric hymn to Demeter. The goddess's name may have meant "barley-mother", incorporating the ancient Cretan word δηαί (dēai), "barley".[35][36] The practice was to dry the barley groats and roast them before preparing the porridge, according to Pliny the Elder's Natural History.[37] Tibetan barley has been a staple food in Tibetan cuisine since the fifth century AD. This grain, along with a cool climate that permitted storage, produced a civilization that was able to raise great armies.[38] It is made into a flour product called tsampa that is still a staple in Tibet.[39] In medieval Europe, bread made from barley and rye was peasant food, while wheat products were consumed by the upper classes.[40]

Taxonomy and varieties

Further information: List of barley cultivars

Two-row and six-row barley

Spikelets are arranged in triplets which alternate along the rachis. In wild barley (and other Old World species of Hordeum), only the central spikelet is fertile, while the other two are reduced. This condition is retained in certain cultivars known as two-row barleys. A pair of mutations (one dominant, the other recessive) result in fertile lateral spikelets to produce six-row barleys.[9] A mutation in one gene, vrs1, is responsible for the transition from two-row to six-row barley.[41]

In traditional taxonomy, different forms of barley were classified as different species based on morphological differences. Two-row barley with shattering spikes (wild barley) was named Hordeum spontaneum (K. Koch). Two-row barley with nonshattering spikes was named as H. distichon (L.), six-row barley with nonshattering spikes as H. vulgare L. (or H. hexastichum L.), and six-row with shattering spikes as H. agriocrithon Åberg. Because these differences were driven by single-gene mutations, coupled with cytological and molecular evidence, most recent classifications treat these forms as a single species, H. vulgare L.[9]

6-row barley has three fertile spikelets per cluster 6-row

barley has three fertile spikelets per cluster

Heads of 2-row and 6-row barley

Two-row and six-row

Hulless barley

Hulless or "naked" barley (Hordeum vulgare L. var. nudum Hook. f.) is a form of domesticated barley with an easier-to-remove hull. Naked barley is an ancient food crop, but a new industry has developed around uses of selected hulless barley to increase the digestibility of the grain, especially for pigs and poultry.[42] Hulless barley has been investigated for several potential new applications as whole grain, bran, and flour.[43]

Barley production – 2022

Country	Millions of tonnes
Russia	23.4
Australia	14.4
France	11.3
Germany	11.2
Canada	10.0
Turkey	8.5
United Kingdom	7.4
Spain	7.0
World	154.9[44]

Production

See also: List of countries by barley production

In 2022, world production of barley was 155 million tonnes, led by Russia accounting for 15% of the world total (table). France, Germany, and Canada were secondary producers. Worldwide barley production was fourth among grains, following maize (1.2 billion tonnes), wheat (808 million tonnes), and rice (776 million tonnes).[45]

Cultivation

Barley is a crop that prefers relatively low temperatures, 15 to 20 °C in the growing season; it is grown around the world in temperate areas. It grows best in well-drained soil in full sunshine. In the tropics and subtropics, it is grown for food and straw in South Asia, North and East Africa, and in the Andes of South America. In dry regions it requires irrigation.[46] It has a short growing season and is relatively droughttolerant.[40] Barley is more tolerant of soil salinity than other cereals, varying in different cultivars.[47] It has less winter-hardiness than winter wheat and far less than rye.[48]

Like other cereals, barley is typically planted on tilled land. Seed was traditionally scattered, but in developed countries is usually drilled. As it grows it requires soil nutrients (nitrogen, phosphorus, potassium), often supplied as fertilizers. It needs to be monitored for pests and diseases, and if necessary treated before these become serious. The stems and ears turn yellow when ripe, and the ears begin to droop. Traditional harvesting was by hand with sickles or scythes; in developed countries, harvesting is mechanised with combine harvesters.[46]

Young winter barley in early November, Scotland, 2009

Young winter barley in early November,

Scotland, 2009

Spraying barley for rust fungus, New Zealand, 1979

Spraying barley for rust fungus,

New Zealand, 1979

Traditional barley harvest by hand with scythes, England, c. 1886. Photo Peter Henry Emerson

Traditional barley harvest by hand with scythes, England, c. 1886.

Photo Peter Henry Emerson

Harvesting winter barley with a combine harvester, Germany, 2017 Harvesting

winter barley with a combine harvester, Germany, 2017

Pests and diseases

Further information: List of barley diseases

Among the insect pests of barley are aphids such as Russian wheat aphid, caterpillars such as of the armyworm moth, barley mealybug, and wireworm larvae of click beetle genera such as Aeolus. Aphid damage can often be tolerated, whereas armyworms can eat whole leaves. Wireworms kill seedlings, and require seed or preplanting treatment.[46]

Serious fungal diseases of barley include powdery mildew caused by Blumeria graminis, leaf scald caused by Rhynchosporium secalis, barley rust caused by Puccinia hordei, crown rust caused by Puccinia coronata, various diseases caused by Cochliobolus sativus, Fusarium ear blight,[49] and stem rust (Puccinia graminis).[50] Bacterial diseases of barley include bacterial blight caused by Xanthomonas campestris pv. translucens.[51] Barley is susceptible to several viral diseases, such as barley mild mosaic bymovirus.[52][53] Some viruses, such as barley yellow dwarf virus, vectored by the rice root aphid, can cause serious crop injury.[54]

For durable disease resistance, quantitative resistance is more important than qualitative resistance. The most important foliar diseases have corresponding resistance gene regions on all chromosomes of barley.[11] A large number of molecular markers are available for breeding of resistance to leaf rust, powdery mildew, Rhynchosporium secalis, Pyrenophora teres f. teres, Barley yellow dwarf virus, and the Barley yellow mosaic virus complex.[55][56]

Wireworms, the larvae of click beetles, kill barley seedlings.

Wireworms, the larvae of click beetles, kill barley seedlings.

Barley rust, a disease caused by the fungus Puccinia hordei

Barley rust, a disease caused by the fungus Puccinia hordei

Food

Cooked barley

Nutritional value per 100 g (3.5 oz)

Energy 515 kJ (123 kcal)

Carbohydrates

28.2 g Sugars
0.3 g
Dietary fiber 3.8 g

Fat

0.4 g

Protein

2.3 g

Vitamins Quantity%DV†

Vitamin A equiv.

beta-Carotene lutein

zeaxanthin 0%0 µg

0%5 µg

56 µg

Thiamine (B1) 7%0.083 mg

Riboflavin (B2) 5%0.062 mg

Niacin (B3) 13%2.063 mg

Pantothenic acid (B5) 3%0.135 mg

Vitamin B6 7%0.115 mg

Folate (B9) 4%16 µg

Vitamin B12 0%0 µg

Choline 2%13.4 mg

Vitamin C 0%0 mg

Vitamin D 0%0 IU

Vitamin E 0%0.01 mg

Vitamin K 1%0.8 µg

Minerals Quantity%DV†
Calcium 1%11 mg

Copper 12%0.105 mg

Iron 7%1.3 mg

Magnesium	5%22 mg

Manganese	11%0.259 mg

Phosphorus	4%54 mg

Potassium	3%93 mg

Sodium 0%3 mg

Zinc	7%0.82 mg

Other constituents	Quantity

Water 68.8 g

Cholesterol	0 mg

Link to USDA Database entry

†Percentages estimated using US recommendations for adults.[57]

Preparation

Hulled barley (or covered barley) is eaten after removing the inedible, fibrous, outer husk or hull. Once removed, it is called dehulled barley (or pot barley or scotch barley).[58] Pearl barley (or pearled barley) is dehulled to remove most of the bran, and polished.[58] Barley meal, a wholemeal barley flour lighter than wheat meal but darker in colour, is used in gruel.[58] This gruel is known as سوي ق : sawīq in the Arab world.[59]

With a long history of cultivation in the Middle East, barley is used in a wide range of traditional Arabic, Assyrian, Israelite, Kurdish, and Persian foodstuffs including Keşkek, kashk, and murri. Barley soup is traditionally eaten during Ramadan in Saudi Arabia.[60] Cholent or hamin (in Hebrew) is a traditional Jewish stew often eaten on Sabbath, in numerous recipes by both Mizrachi and Ashkenazi Jews; its original form was a barley porridge.[61]

In Eastern and Central Europe, barley is used in soups and stews such as ričet. In Africa, where it is a traditional food plant, it has the potential to improve nutrition, boost food security, foster rural development, and support sustainable landcare.[62]

The six-row variety bere is cultivated in Orkney, Shetland, Caithness and the Western Isles of the Scottish Highlands and Islands. When milled into beremeal, it is used locally in bread, biscuits, and the traditional beremeal bannock.[63]

In Japanese cuisine, barley is mixed with rice and steamed as mugimeshi.[64] The naval surgeon Takaki Kanehiro introduced it into institutional cooking to combat beriberi, endemic in the armed forces in the

19th century. It became standard prison fare, and remains a staple in the Japan Self-Defense Forces.[65]

Barley grains with and without the outer husk Barley

grains with and without the outer husk

Beremeal bannock, Orkney, 2008 Beremeal

bannock, Orkney, 2008

Mugimeshi, Japanese steamed barley rice Mugimeshi,

Japanese steamed barley rice

Keşkek, a Middle Eastern barley stew Keşkek,

a Middle Eastern barley stew

Nutrition

Cooked barley is 69% water, 28% carbohydrates, 2% protein, and 0.4% fat (table). In a 100-gram (3.5 oz) reference serving, cooked barley provides 515 kilojoules (123 kcal) of food energy and is a good source (10% or more of the Daily Value, DV) of essential nutrients, including, dietary fibre, the B vitamin niacin (14% DV), and dietary minerals, including iron (10% DV) and manganese (12% DV) (table).[66]

Health implications

According to Health Canada and the US Food and Drug Administration, consuming at least 3 grams per day of barley beta-glucan can lower levels of blood cholesterol, a risk factor for cardiovascular diseases.[67][68] Eating whole-grain barley, a high-fibre grain, improves regulation of blood sugar (i.e., reduces blood glucose response to a meal).[69] Consuming breakfast cereals containing barley over weeks to months improves cholesterol levels and glucose regulation.[70] Barley contains gluten, which makes it an unsuitable grain for consumption by people with gluten-related disorders, such as coeliac disease, non-coeliac gluten sensitivity and wheat allergy sufferers.[71] Nevertheless, some wheat allergy patients can tolerate barley.[72]

Uses

Beer, whisky, and soft drinks

Further information: List of barley-based beverages

Barley, made into malt, is a key ingredient in beer and whisky production.[73] Two-row barley is traditionally used in German and English beers. Six-row barley was traditionally used in US beers, but both varieties are in common usage now.[74] Distilled from green beer,[75] Scottish and Irish whisky are made primarily from barley.[73] About 25% of American barley is used for malting, for which barley is the best-suited grain.[76] Accordingly, barley is often assessed by its malting enzyme content.[11] Barley wine is a style of strong beer from the English brewing tradition. An 18th-century alcoholic drink of the same name was made by boiling barley in water, then mixing the barley water with white wine, borage, lemon and sugar. In the 19th century, a different barley wine was prepared from recipes of ancient Greek origin.[3]

Nonalcoholic drinks such as barley water[3] and roasted barley tea have been made by boiling barley in water.[77] In Italy, roasted barley is sometimes used as coffee substitute, caffè d'orzo (barley coffee).[78]

Traditional floor malting in Scotland for malt whisky Traditional

floor malting in Scotland for malt whisky

Barley grains being mashed (heated with water) for brewing beer Barley

grains being mashed (heated with water) for brewing beer

Scotch whisky and beer are both made from barley.

Scotch whisky and beer are both made from barley.

Boricha, Korean roasted barley tea

Boricha, Korean

roasted barley tea

Animal feed

Barley-based animal feed pellets

Some 70% of the world's barley production is used as livestock feed,[79] for example for cattle feeding in western Canada.[80] In 2014, an enzymatic process was devised to make a high-protein fish feed from barley, suitable for carnivorous fish such as trout and salmon.[81]

Other uses

Barley straw has been placed in mesh bags and floated in fish ponds or water gardens to help prevent algal growth without harming pond plants and animals. The technique's effectiveness is at best mixed.[82] Barley grains were once used for measurement in England, there being nominally three or four barleycorns to the inch.[83] By the 19th century, this had been superseded by standard inch measures.[84] In ancient Mesopotamia, barley was used as a form of money, the standard unit of weight for barley, and hence of value, being the shekel.[85]

Culture and folklore

In English folklore, the figure of John Barleycorn in the folksong of the same name is a personification of barley, and of the alcoholic beverages made from it: beer and whisky. In the song, John Barleycorn is represented as suffering attacks, death, and indignities that correspond to the various stages of barley cultivation, such as reaping and malting; but he is revenged by getting the men drunk: "And little Sir John and the nut-brown bowl / Proved the strongest man at last."[86][87] The folksong "Elsie Marley" celebrates an alewife of County Durham with lines such as "And do you ken Elsie Marley, honey? / The wife that sells the barley, honey". The antiquary Cuthbert Sharp records that Elsie Marley was "a handsome, buxom, bustling landlady, and brought good custom to the [ale] house by her civility and attention."[88]

English pub names such as The Barley Mow,[89] John Barleycorn,[86] Malt Shovel,[90] and Mash Tun[91] allude to barley's role in the production of beer ture to achieve significant yield improvements.

Maize

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Not to be confused with Maze.

This article is about the commonly grown cereal grain. For other uses, see Maize (disambiguation).

"Corn" redirects here. For other uses, see Corn (disambiguation).

Maize

Botanical illustration showing male and female flowers

Includes male and female flowers

Conservation status

Least Concern (IUCN 3.1)[1]

Scientific classificationEdit this classification

Kingdom: Plantae

Clade: Tracheophytes

Clade: Angiosperms Clade:

Monocots

Clade: Commelinids

Order: Poales

Family: Poaceae

Subfamily: Panicoideae

Genus: Zea

Species: Z. mays

Binomial name

Zea mays

L.

Maize /meɪz/ (Zea mays), also known as corn in North American and Australian English, is a tall stout grass that produces cereal grain. It was domesticated by indigenous peoples in southern Mexico about 9,000 years ago from wild teosinte. Native Americans planted it alongside beans and squashes in the Three Sisters polyculture. The leafy stalk of the plant gives rise to male inflorescences or tassels which produce pollen, and female inflorescences called ears which yield grain, known as kernels or seeds. In modern commercial varieties, these are usually yellow or white; other varieties can be of many colors.

Maize relies on humans for its propagation. Since the Columbian exchange, it has become a staple food in many parts of the world, with the total production of maize surpassing that of wheat and rice. Much maize is used for animal feed, whether as grain or as the whole plant, which can either be baled or made into the more palatable silage. Sugar-rich varieties called sweet corn are grown for human consumption, while field corn varieties are used for animal feed, for uses such as cornmeal or masa, corn starch, corn syrup, pressing into corn oil, alcoholic beverages like bourbon whiskey, and as chemical feedstocks including ethanol and other biofuels.

Maize is cultivated throughout the world; a greater weight of maize is produced each year than any other grain. In 2020, world production was 1.1 billion tonnes. It is afflicted by many pests and diseases; two major insect pests, European corn borer and corn rootworms, have each caused annual losses of a billion dollars in the US. Modern plant breeding has greatly increased output and qualities such as nutrition, drought, and tolerance of pests and diseases. Much maize is now genetically modified.

As a food, maize is used to make a wide variety of dishes including Mexican tortillas and tamales, Italian polenta, and American hominy grits. Maize protein is low in some essential amino acids, and the niacin it contains only becomes available if freed by alkali treatment. In Mesoamerica, maize is personified as a maize god and depicted in sculptures.

History

Pre-Columbian development

Ancient Mesoamerican relief sculpture of maize, National Museum of Anthropology of Mexico

Maize requires human intervention for it to propagate. The kernels of its naturally-propagating teosinte ancestor fall off the cob on their own, while those of domesticated maize do not.[2] All maize arose from a single domestication in southern Mexico about 9,000 years ago. The oldest surviving maize types are those of the Mexican highlands. Maize spread from this region to the lowlands and over the Americas along two major paths.[3] The centre of domestication was most likely the Balsas River valley of southcentral Mexico.[4] Maize reached highland Ecuador at least 8000 years ago.[5] It reached lower Central America by 7600 years ago, and the valleys of the Colombian Andes between 7000 and 6000 years ago.[4]

The earliest maize plants grew a single, small corn ear per plant.[6] The Olmec and Maya cultivated maize in numerous varieties throughout Mesoamerica; they cooked, ground and processed it through nixtamalization.[7] By 3000 years ago, maize was central to Olmec culture, including their calendar, language, and myths.[8]

The Mapuche people of south-central Chile cultivated maize along with quinoa and potatoes in preHispanic times.[9] Before the expansion of the Inca Empire, maize was traded and transported as far south as 40° S in Melinquina, Lácar Department, Argentina, probably brought across the Andes from Chile.[10]

Columbian exchange

Further information: Columbian exchange

Cultivation of maize, in an illustration from the 16th c. Florentine Codex

After the arrival of Europeans in 1492, Spanish settlers consumed maize, and explorers and traders carried it back to Europe. Spanish settlers much preferred wheat bread to maize. Maize flour could not be substituted for wheat for communion bread, since in Christian belief at that time only wheat could undergo transubstantiation and be transformed into the body of Christ.[11]

Maize spread to the rest of the world because of its ability to grow in diverse climates. It was cultivated in Spain just a few decades after Columbus's voyages and then spread to Italy, West Africa and elsewhere.[11] By the 17th century, it was a common peasant food in Southern Europe. By the 18th century, it was the chief food of the southern French and Italian peasantry, especially as polenta in Italy.[12]

When maize was introduced into Western farming systems, it was welcomed for its productivity. However, a widespread problem of malnutrition soon arose wherever it had become a staple food.[13] Indigenous Americans had learned to soak maize in alkali-water — made with ashes and lime — since at least 1200–1500 BC, creating the process of nixtamalization. They did this to liberate the corn hulls, but coincidentally it also liberated the B-vitamin niacin, the lack of which caused pellagra.[14] Once alkali processing and dietary variety were understood and applied, pellagra disappeared in the developed world. The development of high-lysine maize and the promotion of a more balanced diet have contributed to its demise. Pellagra still exists in food-poor areas and refugee camps where people survive on donated maize.[15]

Names

The name maize derives from the Spanish form maíz of the Taíno mahis.[16] The Swedish botanist Carl Linnaeus used the common name maize as the species epithet in Zea mays.[17] The name Maize is preferred in formal, scientific, and international usage as a common name because it refers specifically to this one grain, unlike corn, which has a complex variety of meanings that vary by context and geographic region.[18] Most countries primarily use the term maize, and the name corn is used mainly in the United States and a handful of other English-speaking countries.[19][20] In countries that primarily use the term maize, the word "corn" may denote any cereal crop, varying geographically with the local staple,[21] such as wheat in England and oats in Scotland or Ireland.[18] The usage of corn for maize started as a shortening of "Indian corn" in 18th century North America.[22]

The historian of food Betty Fussell writes in an article on the history of the word "corn" in North America that "[t]o say the word "corn" is to plunge into the tragi-farcical mistranslations of language and history".[8] Similar to the British usage, the Spanish referred to maize as panizo, a generic term for cereal grains, as did Italians with the term polenta. The British later referred to maize as Turkey wheat, Turkey corn, or Indian corn; Fussell comments that "they meant not a place but a condition, a savage rather than a civilized grain".[8]

International groups such as the Centre for Agriculture and Bioscience International consider maize the preferred common name.[23] The word maize is used by the UN's FAO,[24] and in the names of the International Maize and Wheat Improvement Center of Mexico, the Indian Institute of Maize Research,[25] the Maize Association of Australia,[26] the National Maize Association of Nigeria,[27] the National Maize Association of Ghana,[28] the Maize Trust of South Africa,[29] and the Zimbabwe Seed Maize Association.[30]

Structure and physiology

Parts of a maize plant

Maize is a tall annual grass with a single stem, ranging in height from 1.2 m (4 ft) to 4 m (13 ft).[31] The long narrow leaves arise from the nodes or joints, alternately on opposite sides on the stalk.[31] Maize is monoecious, with separate male and female flowers on the same plant.[31] At the top of the stem is the tassel, an inflorescence of male flowers; their anthers release pollen, which is dispersed by wind.[31] Like other pollen, it is an allergen, but most of it falls within a few meters of the tassel and the risk is largely restricted to farm workers.[32] The female inflorescence, some way down the stem from the tassel, is first seen as a silk, a bundle of soft tubular hairs, one for the carpel in each female flower, which develops into a kernel (often called a seed. Botanically, as in all grasses, it is a fruit, fused with the seed coat to form a caryopsis[33]) when it is pollinated.[31] A whole female inflorescence develops into an ear or corncob, enveloped by multiple leafy layers or husks.[31] The ear leaf is the leaf most closely associated with a particular developing ear. This leaf and those above it contribute over three quarters of the carbohydrate (starch) that fills the grain.[34]

The grains are usually yellow or white in modern varieties; other varieties have orange, red, brown, blue, purple, or black grains. They are arranged in 8 to 32 rows around the cob; there can be up to 1200 grains on a large cob.[6] Yellow maizes derive their color from carotenoids; red maizes are colored by anthocyanins and phlobaphenes; and orange and green varieties may contain combinations of these pigments.[35]

Maize has short-day photoperiodism, meaning that it requires nights of a certain length to flower. Flowering further requires enough warm days above 10 °C (50 °F). The control of flowering is set genetically; the physiological mechanism involves the phytochrome system. Tropical cultivars can be problematic if grown in higher latitudes, as the longer days can make the plants grow tall instead of setting seed before winter comes. On the other hand, growing tall rapidly could be convenient for producing biofuel.[31]

Immature maize shoots accumulate a powerful antibiotic substance, 2,4-dihydroxy-7-methoxy-1,4benzoxazin-3-one (DIMBOA), which provides a measure of protection against a wide range of pests.[36] Because of its shallow roots, maize is susceptible to droughts, intolerant of nutrient-deficient soils, and prone to being uprooted by severe winds.[37]

Many small male flowers make up the male inflorescence, called the tassel. Many

small male flowers make up the male inflorescence, called the tassel.

Female inflorescence, with young silk Female

inflorescence, with young silk Stalks, ears

and silk Stalks, ears and silk

Full-grown maize plants Full-grown

maize plants

Mature maize ear on a stalk Mature

maize ear on a stalk

Male flowers

Male flowers

Mature silk

Mature silk

Genomics and genetics

Exotic varieties are collected to add genetic diversity when selectively breeding new domestic strains.

Maize is diploid with 20 chromosomes. 83% of allelic variation within the genome derives from its teosinte ancestors, primarily due to the freedom of Zea species to outcross.[38] Barbara McClintock used maize to validate her transposon theory of "jumping genes", for which she won the 1983 Nobel Prize in Physiology or Medicine.[39] Maize remains an important model organism for genetics and developmental biology.[40] The MADS-box motif is involved in the development of maize flowers.[41]

The Maize Genetics and Genomics Database is funded by the US Department of Agriculture to support maize research.[42] The International Maize and Wheat Improvement Center maintains a large collection of maize accessions tested and cataloged for insect resistance.[43] In 2005, the US National Science Foundation, Department of Agriculture, and the Department of Energy formed a consortium to sequence the maize genome. The resulting DNA sequence data was deposited immediately into GenBank, a public repository for genome-sequence data.[44] Sequencing of the maize genome was completed in 2008.[45] In 2009, the consortium published results of its sequencing effort.[46] The genome, 85% of which is composed of transposons, contains 32,540 genes. Much of it has been duplicated and reshuffled by helitrons, a group of transposable elements within maize's DNA.[47]

Breeding

Conventional breeding

Maize breeding in prehistory resulted in large plants producing large ears. Modern breeding began with individuals who selected highly productive varieties in their fields and then sold seed to other farmers. James L. Reid was one of the earliest and most successful, developing Reid's Yellow Dent in the 1860s. These early efforts were based on mass selection (a row of plants is grown from seeds of one parent), the choosing of plants after pollination (which means that only the female parents are known). Later breeding efforts included ear to row selection (C. G. Hopkins c. 1896), hybrids made from selected inbred lines (G. H. Shull, 1909), and the highly successful double cross hybrids using four inbred lines (D. F. Jones c. 1918, 1922). University-supported breeding programs were especially important in developing and introducing modern hybrids.[48]

Since the 1940s, the best strains of maize have been first-generation hybrids made from inbred strains that have been optimized for specific traits, such as yield, nutrition, drought, pest and disease tolerance. Both conventional cross-breeding and genetic engineering have succeeded in increasing output and reducing the need for cropland, pesticides, water and fertilizer. There is conflicting evidence to support the hypothesis that maize yield potential has increased over the past few decades. This suggests that changes in yield potential are associated with leaf angle, lodging resistance, tolerance of high plant density, disease/pest tolerance, and other agronomic traits rather than increase of yield potential per individual plant.[49]

Certain varieties of maize have been bred to produce many ears; these are the source of the "baby corn" used as a vegetable in Asian cuisine.[50][51] A fast-flowering variety named mini-maize was developed to aid scientific research, as multiple generations can be obtained in a single year.[52] One strain called olotón has evolved a symbiotic relationship with nitrogen-fixing microbes, which provides the plant with 29%–82% of its nitrogen.[53] The International Maize and Wheat Improvement Center (CIMMYT) operates a conventional breeding program to provide optimized strains. The program began in the 1980s.[54] Hybrid seeds are distributed in Africa by its Drought Tolerant Maize for Africa project.[55]

Tropical landraces remain an important and underused source of resistance alleles – both those for disease and for herbivores. Such alleles can then be introgressed into productive varieties.[56] Rare alleles for this purpose were discovered by Dao and Sood, both in 2014.[56] In 2018, Zerka Rashid of CIMMYT used its association mapping panel, developed for tropical drought tolerance traits. to find new genomic regions providing sorghum downy mildew resistance, and to further characterize known differentially methylated regions.[57]

Genetic engineering

Main article: Transgenic maize

Genetically modified maize was one of the 26 genetically engineered food crops grown commercially in 2016.[58][59] The vast majority of this is Bt maize. Genetically modified maize has been grown since 1997 in the United States and Canada;[60] by 2016, 92% of the US maize crop was genetically modified.[58] As of 2011, herbicide-tolerant maize and insect-resistant maize varieties were each grown in over 20 countries.[61] In September 2000, up to $50 million worth of food products were recalled due to the presence of Starlink genetically modified corn, which had been approved only for animal consumption.[62]

Origin

External phylogeny

The maize genus Zea is relatively closely related to sorghum, both being in the PACMAD clade of Old World grasses, and much more distantly to rice and wheat, which are in the other major group of grasses, the BOP clade. It is closely related to Tripsacum, gamagrass.[63]

(Part of Poaceae) BOP

clade

various grasses e.g. fescue, ryegrass

Hordeum (barley)

Triticum (wheat)

Oryza (rice)

PACMAD clade

Pennisetum (fountaingrasses)

Sorghum (sorghum)

Tripsacum (gamagrass)

Zea

Zea mays (maize)

other Zea species (teosintes)

Maize and teosinte

See also: Origin of maize and interaction with teosintes

Teosinte (left), maize-teosinte hybrid (middle), maize (right)

Maize is the domesticated variant of the four species of teosintes, which are its crop wild relatives.[64] The teosinte origin theory was proposed by the Russian botanist Nikolai Ivanovich Vavilov in 1931, and the American Nobel Prize-winner George Beadle in 1932.[65]: 10 The two plants have dissimilar appearance, maize having a single tall stalk with multiple leaves and teosinte being a short, bushy plant. The difference between the two is largely controlled by differences in just two genes, called grassy tillers1 (gt1, A0A317YEZ1) and teosinte branched-1 (tb1, Q93WI2).[64] In the late 1930s, Paul Mangelsdorf suggested that domesticated maize was the result of a hybridization event between an unknown wild maize and a species of Tripsacum, a related genus; this has been refuted by modern genetic testing.[65]

In 2004, John Doebley identified Balsas teosinte, Zea mays ssp. parviglumis, native to the Balsas River valley in Mexico's southwestern highlands, as the crop wild relative genetically most similar to modern maize.[66][67] The middle part of the short Balsas River valley is the likely location of early domestication. Stone milling tools with maize residue have been found in an 8,700 year old layer of deposits in a cave not far from Iguala, Guerrero.[68] Doebley and colleagues showed in 2002 that maize had been domesticated only once, about 9,000 years ago, and then spread throughout the Americas.[3]

Maize pollen dated to 7,300 years ago from San Andres, Tabasco has been found on the Caribbean coast.[68] A primitive corn was being grown in southern Mexico, Central America, and northern South America 7,000 years ago. Archaeological remains of early maize ears, found at Guila Naquitz Cave in the Oaxaca Valley, are roughly 6,250 years old; the oldest ears from caves near Tehuacan, Puebla, are 5,450 years old.[7]

Spreading to the north

Around 4,500 years ago, maize began to spread to the north. In the United States, maize was first cultivated at several sites in New Mexico and Arizona about 4,100 years ago.[7] During the first millennium AD, maize cultivation spread more widely in the areas north. In particular, the large-scale adoption of maize agriculture and consumption in eastern North America took place about A.D. 900. Native Americans cleared large forest and grassland areas for the new crop.[69] The rise in maize cultivation 500 to 1,000 years ago in what is now the southeastern United States corresponded with a decline of freshwater mussels, which are very sensitive to environmental changes.[70]

Agronomy

Growing

Because it is cold-intolerant, in the temperate zones maize must be planted in the spring. Its root system is generally shallow, so the plant is dependent on soil moisture. As a plant that uses C4 carbon fixation, maize is a considerably more water-efficient crop than plants that use C3 carbon fixation such as alfalfa and soybeans. Maize is most sensitive to drought at the time of silk emergence, when the flowers are ready for pollination. In the United States, a good harvest was traditionally predicted if the maize was "knee-high by the Fourth of July", although modern hybrids generally exceed this growth rate. Maize used for silage is harvested while the plant is green and the fruit immature. Sweet corn is harvested in the "milk stage", after pollination but before starch has formed, between late summer and early to midautumn. Field maize is left in the field until very late in the autumn to thoroughly dry the grain, and may, in fact, sometimes not be harvested until winter or even early spring. The importance of sufficient soil moisture is shown in many parts of Africa, where periodic drought regularly causes maize crop failure and consequent famine. Although it is grown mainly in wet, hot climates, it can thrive in cold, hot, dry or wet conditions, meaning that it is an extremely versatile crop.[71]

Maize was planted by the Native Americans in small hills of soil, in the polyculture system called the Three Sisters.[72] Maize provided support for beans; the beans provided nitrogen derived from nitrogenfixing rhizobia bacteria which live on the roots of beans and other legumes; and squashes provided ground cover to stop weeds and inhibit evaporation by providing shade over the soil.[73]

Seedlings three weeks after sowing Seedlings

three weeks after sowing

Young stalks

Young stalks

Mature plants showing ears Mature

plants showing ears

Harvesting

Sweet corn, harvested earlier than maize grown for grain, grows to maturity in a period of from 60 to 100 days according to variety. An extended sweet corn harvest, picked at the milk stage, can be arranged either by planting a selection of varieties which ripen earlier and later, or by planting different areas at fortnightly intervals.[74] Maize harvested as a grain crop can be kept in the field a relatively long time, even months, after the crop is ready to harvest; it can be harvested and stored in the husk leaves if kept dry.[75]

Before World War II, most maize in North America was harvested by hand. This involved a large number of workers and associated social events (husking or shucking bees). From the 1890s onward, some machinery became available to partially mechanize the processes, such as one- and two-row mechanical pickers (picking the ear, leaving the stover) and corn binders, which are reaper-binders designed specifically for maize. The latter produce sheaves that can be shocked. By hand or mechanical picker, the entire ear is harvested, which requires a separate operation of a maize sheller to remove the kernels from the ear. Whole ears of maize were often stored in corn cribs, sufficient for some livestock feeding uses. Today corn cribs with whole ears, and corn binders, are less common because most modern farms harvest the grain from the field with a combine harvester and store it in bins. The combine with a corn head (with points and snap rolls instead of a reel) does not cut the stalk; it simply pulls the stalk down. The stalk continues downward and is crumpled into a mangled pile on the ground, where it usually is left to become organic matter for the soil. The ear of maize is too large to pass between slots in a plate as the snap rolls pull the stalk away, leaving only the ear and husk to enter the machinery. The combine separates the husk and the cob, keeping only the kernels.[76]

Harvesting maize, Iowa Harvesting

maize, Iowa

Harvesting maize, Finland Harvesting

maize, Finland

Hand-picking maize, Myanmar Hand-picking

maize, Myanmar

Grain storage

Drying is vital to prevent or at least reduce damage by mould fungi, which contaminate the grain with mycotoxins. Aspergillus and Fusarium spp. are the most common mycotoxin sources, and accordingly important in agriculture.[60] If the moisture content of the harvested grain is too high, grain dryers are used to reduce the moisture content by blowing heated air through the grain. This can require large amounts of energy in the form of combustible gases (propane or natural gas) and electricity to power the blowers.[77]

Production

Further information: Corn production in the United States

Maize is widely cultivated throughout the world, and a greater weight of maize is produced each year than any other grain.[78] In 2020, total world production was 1.16 billion tonnes, led by the United States with 31.0% of the total (table). China produced 22.4% of the global total.[79]

Top Maize producers in

2020

Numbers in million tonnes

1. United States 360.3 (31%)
2. China 260.7 (22.43%)
3. Brazil 104 (8.95%)

4. Argentina 58.4 (5.02%)

5. Ukraine 30.3 (2.61%)

6. India 30.2 (2.6%)

7. Mexico 27.4 (2.36%)

8. Indonesia 22.5 (1.94%)

9. South Africa 15.3 (1.32%)

10. Russia 13.9 (1.2%) World total 1162.4

Source: FAOSTAT[80][79]

Production of maize (2019)[81] Production

of maize (2019)[81]

Maize (pink strip) is the second most widely produced primary crop, after sugarcane, and the first among grain crops.[82]

Maize (pink strip) is the second most widely produced primary crop, after sugarcane, and the first among grain crops.[82]

Pests

Disease cycle of Northern corn leaf blight

Further information: List of maize diseases

Many pests can affect maize growth and development, including invertebrates, weeds, and pathogens.[83][84]

Maize is susceptible to a large number of fungal, bacterial, and viral plant diseases. Those of economic importance include diseases of the leaf, smuts such as corn smut, ear rots and stalk rots.[85] Northern corn leaf blight damages maize throughout its range, whereas banded leaf and sheath blight is a problem in Asia.[86][87] Some fungal diseases of maize produce potentially dangerous mycotoxins such as aflatoxin.[60] In the United States, major diseases include tar spot, bacterial leaf streak, gray leaf spot, northern corn leaf blight, and Goss's wilt; in 2022, the most damaging disease was tar spot, which caused losses of 116.8 million bushels.[88]

Maize sustains a billion dollars' worth of losses annually in the US from each of two major insect pests, namely the European corn borer or ECB (Ostrinia nubilalis) and corn rootworms (Diabrotica spp) western corn rootworm, northern corn rootworm, and southern corn rootworm.[89][90][91] Another serious pest is the fall armyworm (Spodoptera frugiperda).[92] The maize weevil (Sitophilus zeamais) is a serious pest of stored grain.[93] The Northern armyworm, Oriental armyworm or Rice ear-cutting caterpillar (Mythimna separata) is a major pest of maize in Asia.[94]

Nematodes too are pests of maize. It is likely that every maize plant harbors some nematode parasites, and populations of Pratylenchus lesion nematodes in the roots can be "enormous". The effects on the plants include stunting, sometimes of whole fields, sometimes in patches, especially when there is also water stress and poor control of weeds.[95]

Many plants, both monocots (grasses) such as Echinochloa crus-galli (barnyard grass) and dicots (forbs) such as Chenopodium and Amaranthus may compete with maize and reduce crop yields. Control may involve mechanical weed removal, flame weeding, or herbicides.[96]

Caterpillar of European corn borer in maize Caterpillar

of European corn borer in maize

Corncob damage by European corn borer

Corncob damage by European corn borer

Uses

Culinary

Further information: List of maize dishes

Maize and cornmeal (ground dried maize) constitute a staple food in many regions of the world.[6] Maize is used to produce the food ingredient cornstarch.[97] Maize starch can be hydrolyzed and enzymatically treated to produce high fructose corn syrup, a sweetener.[98] Maize may be fermented and distilled to produce Bourbon whiskey.[99] Corn oil is extracted from the germ of the grain.[100]

In prehistoric times, Mesoamerican women used a metate quern to grind maize into cornmeal. After ceramic vessels were invented the Olmec people began to cook maize together with beans, improving the nutritional value of the staple meal. Although maize naturally contains niacin, an important nutrient, it is not bioavailable without the process of nixtamalization. The Maya used nixtamal meal to make porridges and tamales.[101] Maize is a staple of Mexican cuisine. Masa (nixtamal) is the main ingredient for tortillas, atole and many other dishes of Central American food. It is the main ingredient of corn tortilla, tamales, atole and the dishes based on these.[102] The corn smut fungus, known as huitlacoche, which grows on maize, is a Mexican delicacy.[103]

Coarse maize meal is made into a thick porridge in many cultures: from the polenta of Italy, the angu of Brazil, the mămăligă of Romania, to cornmeal mush in the US (or hominy grits in the Southern US) or the food called mieliepap in South Africa and sadza, nshima, ugali and other names in other parts of Africa. Introduced into Africa by the Portuguese in the 16th century, maize has become Africa's most important staple food crop.[104]

Sweet corn, a genetic variety that is high in sugars and low in starch, is eaten in the unripe state as corn on the cob.[105]

Poster of maize-based foods, US Food Administration, 1918

Poster of maize-based foods,

US Food Administration, 1918

Semi-peeled corn on the cob Semi-peeled

corn on the cob Mexican tamales

Mexican tamales

One way of serving Italian polenta

One way of serving Italian polenta

Nutritional value

Sweetcorn, yellow, raw

(seeds only)

Note: assuming freed niacin

Nutritional value per 100 g (3.5 oz)

Energy 360 kJ (86 kcal)

Carbohydrates

18.7 g

Starch 5.7 g

Sugars 6.26 g

Dietary fiber 2 g

Fat

1.35 g

Protein

3.27 g

Tryptophan 0.023 g

Threonine 0.129 g

Isoleucine 0.129 g

Leucine 0.348 g

Lysine 0.137 g

Methionine 0.067 g

Cystine 0.026 g

Phenylalanine 0.150 g

Tyrosine 0.123 g

Valine 0.185 g

Arginine 0.131 g

Histidine 0.089 g

Alanine 0.295 g

Aspartic acid 0.244 g

Glutamic acid 0.636 g

Glycine 0.127 g

Proline 0.292 g

Serine 0.153 g

Vitamins Quantity%DV†

Vitamin A equiv.

lutein zeaxanthin 1%9

µg

644 µg

Thiamine (B1) 13%0.155 mg

Riboflavin (B2) 4%0.055 mg

Niacin (B3) 11%1.77 mg

Pantothenic acid (B5) 14%0.717 mg

Vitamin B6 5%0.093 mg

Folate (B9) 11%42 µg Vitamin

C 8%6.8 mg

Minerals Quantity%DV†

Iron 3%0.52 mg

Magnesium 9%37 mg

Manganese 7%0.163 mg

Phosphorus 7%89 mg

Potassium 9%270 mg

Zinc 4%0.46 mg

Other constituents Quantity Water 75.96 g

Link to USDA Database entry

One ear of medium size (6-3/4" to 7-1/2" long) maize

has 90 grams of seeds.

†Percentages estimated using US recommendations for adults.[106]

Raw, yellow, sweet maize kernels are composed of 76% water, 19% carbohydrates, 3% protein, and 1% fat (table). In a 100-gram serving, maize kernels provide 86 calories and are a good source (10–19% of the Daily Value) of the B vitamins, thiamin, niacin (if freed), pantothenic acid (B5) and folate.[107] Maize has suboptimal amounts of the essential amino acids tryptophan and lysine, which accounts for its lower status as a protein source.[108] The proteins of beans and legumes complement those of maize.[108]

Animal feed

See also: Corn stover § Uses

Maize is a major source of animal feed. As a grain crop, the dried kernels are used as feed. They are often kept on the cob for storage in a corn crib, or they may be shelled off for storage in a grain bin. When the grain is used for feed, the rest of the plant (the corn stover) can be used later as fodder, bedding (litter), or soil conditioner. When the whole maize plant (grain plus stalks and leaves) is used for fodder, it is usually chopped and made into silage, as this is more digestible and more palatable to ruminants than the dried form.[109] Traditionally, maize was gathered into shocks after harvesting, where it dried further. It could then be stored for months until fed to livestock. Silage can be made in silos or in silage wrappers. In the tropics, maize is harvested year-round and fed as green forage to the animals.[110] Baled cornstalks offer an alternative to hay for animal feed, alongside direct grazing of maize grown for this purpose.[111]

Cattle wait alongside a fence as a truck distributes a grain feed composed of corn by-products into troughs.

Cattle wait alongside a fence as a truck distributes a grain feed composed of corn by-products into troughs.

Baled cornstalks

Baled cornstalks

Chemicals

Starch from maize can be made into plastics, fabrics, adhesives, and many other chemical products.[112] Corn steep liquor, a plentiful watery byproduct of maize wet milling process, is used in the biochemical industry and research as a culture medium to grow microorganisms.[113]

Biofuel

See also: Corn ethanol and Corn stover

Feed maize is being used for heating; specialized corn stoves (similar to wood stoves) use either feed maize or wood pellets to generate heat. Maize cobs can be used as a biomass fuel source. Home-heating furnaces which use maize kernels as a fuel have a large hopper that feeds the kernels into the fire.[114] Maize is used as a feedstock for the production of ethanol fuel.[115] The price of food is indirectly affected by the use of maize for biofuel production: use of maize for biofuel production increases the demand, and therefore the price of maize.[116] A pioneering biomass gasification power plant in Strem, Burgenland, Austria, started operating in 2005. It would be possible to create diesel from the biogas by the Fischer Tropsch method.[117]

Farm-based maize silage digester near Neumünster, Germany, 2007, using whole maize plants, not just the grain. The green tarpaulin top cover is held up by the biogas stored in the digester.

Farm-based maize silage digester near Neumünster, Germany, 2007, using whole maize plants, not just the grain. The green tarpaulin top cover is held up by the biogas stored in the digester.

In human culture

In Mesoamerica, maize is seen as a vital force, personified as a maize god, usually female.[118] In the

United States, maize ears are carved into column capitals in the United States Capitol building.[119] The Corn Palace in Mitchell, South Dakota, uses cobs and ears of colored maize to implement a mural design that is recycled annually.[120] The concrete Field of Corn sculpture in Dublin, Ohio depicts hundreds of ears of corn in a grassy field.[121] A maize stalk with two ripe ears is depicted on the reverse of the Croatian 1 lipa coin, minted since 1993.

Sorghum

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For other uses, see Sorghum (disambiguation).

"Sorgo" redirects here. For the Ragusan family, see Sorgo (family).

Sorghum

S. bicolor

Scientific classificationEdit this classification

Kingdom: Plantae

Clade: Tracheophytes

Clade: Angiosperms Clade:

Monocots

Clade: Commelinids

Order: Poales

Family: Poaceae

Subfamily: Panicoideae

Supertribe: Andropogonodae

Tribe: Andropogoneae

Subtribe: Saccharinae

Genus: Sorghum

Moench 1794, conserved name not Sorgum Adanson 1763

Type species

S. bicolor

(L.) Moench

Synonyms[1]

Blumenbachia Koeler 1802, rejected name not Schrad. 1825 (Loasaceae)

Sarga Ewart

Vacoparis Spangler

Andropogon Hackel.

Sorghum (/ˈsɔːrgəm/) or broomcorn is a genus of about 25 species of flowering plants in the grass family (Poaceae). Some of these species are grown as cereals for human consumption, in pastures for animals as fodder, and as bristles for brooms.[2] Sorghum grain is a nutritious food rich in protein, dietary fiber, B vitamins, and minerals.

Sorghum is either cultivated in warm climates worldwide or naturalized in open plains.[3] In 2021, world production of sorghum was 61 million tonnes, with the United States as the leading grower.

History

Sorghum was domesticated from its wild ancestor more than 5,000 years ago in what is today Sudan. The newest evidence comes from an archaeological site near Kassala in eastern Sudan, dating from 3500 to 3000 BC, and is associated with the neolithic Butana Group culture.[4] It was the staple food of the kingdom of Alodia.[5]

Taxonomy

Sorghum is in the grass family, Poaceae, in the subfamily Panicoideae, in the tribe Andropogoneae – the same as maize (Zea mays), big bluestem (Andropogon gerardi), and sugarcane (Saccharum spp.).

Species

Accepted species recorded include:[6]

Heap at a West African market

West African market

A plate of sorghum grain

Sorghum amplum – northwestern Australia

Sorghum angustum – Queensland

Sorghum arundinaceum – Africa, Indian Subcontinent, Madagascar, islands of the western Indian Ocean

Sorghum bicolor – cultivated sorghum, often individually called sorghum, also known as durra, jowari, or milo. Native to Sahel region of Africa; naturalized in many places

Sorghum brachypodum – Northern Territory of Australia

Sorghum bulbosum – Northern Territory, Western Australia

Sorghum burmahicum – Thailand, Myanmar

Sorghum controversum – India

Sorghum × drummondii – Sahel and West Africa

Sorghum ecarinatum – Northern Territory, Western Australia

Sorghum exstans – Northern Territory of Australia

Sorghum grande – Northern Territory, Queensland

Sorghum halepense – Johnson grass – North Africa, islands of eastern Atlantic, southern Asia from Lebanon to Vietnam; naturalized in East Asia, Australia, the Americas

Sorghum interjectum – Northern Territory, Western Australia

Sorghum intrans – Northern Territory, Western Australia

Sorghum laxiflorum – Philippines, Lesser Sunda Islands, Sulawesi, New Guinea, northern Australia

Sorghum leiocladum – Queensland, New South Wales, Victoria

Sorghum macrospermum – Northern Territory of Australia

Sorghum matarankense – Northern Territory, Western Australia

Sorghum nitidum – East Asia, Indian Subcontinent, Southeast Asia, New Guinea, Micronesia

Sorghum plumosum – Australia, New Guinea, Indonesia

Sorghum propinquum – China, Indian Subcontinent, Southeast Asia, New Guinea, Christmas Island, Micronesia, Cook Islands

Sorghum purpureosericeum – Sahel from Mali to Tanzania; Yemen, Oman, India

Sorghum stipoideum – Northern Territory, Western Australia

Sorghum timorense – Lesser Sunda Islands, Maluku, New Guinea, northern Australia

Sorghum trichocladum – Mexico, Guatemala, Honduras

Sorghum versicolor – eastern + southern Africa from Ethiopia to Namibia; Oman

Sorghum virgatum – dry regions from Senegal to the Levant.

Sorghum production – 2021

Country	(Millions of tonnes)
United States	11.4
India	4.8
Ethiopia	4.4
Mexico	4.4
Argentina	3.3
China	3.0
World	61.4

Source: FAOSTAT of the United Nations[7]

Genetics and genomics

Agrobacterium transformation can be used on this genus,[8] as shown in a 2018 report of such a transformation system.[8] A 2013 study developed and validated an SNP array for molecular breeding.[9][10]

Distribution and habitat

Seventeen of the 25 species are native to Australia,[11][12][13][14] with the range of some extending to Africa, Asia, Mesoamerica, and certain islands in the Indian and Pacific Oceans.[15][16]

Production

In 2021, world production of sorghum was 61 million tonnes, led by the United States with 19% of the total (table). India, Ethiopia, and Mexico were secondary producers.

Sorghum grain

Nutritional value per 100 g (3.5 oz)

Energy 329 kJ (79 kcal)

Carbohydrates

72.1 g

Sugars 2.53 g

Dietary fiber 6.7 g

Fat

3.46 g

Saturated 0.61 g

Monounsaturated 1.13 g

Polyunsaturated 1.56 g

Protein

10.6 g

Vitamins Quantity%DV†

Vitamin A equiv. 0%0 µg

Thiamine (B1) 28%0.332 mg

Riboflavin (B2) 7%0.096 mg

Niacin (B3) 23%3.69 mg

Pantothenic acid (B5) 7%0.367 mg

Vitamin B6 26%0.443 mg

Folate (B9) 5%20 µg

Vitamin C 0%0 mg

Vitamin E 3%0.5 mg

Minerals Quantity%DV†

Calcium 1%13 mg

Copper 32%0.284 mg

Iron 19%3.36 mg

Magnesium 39%165 mg

Manganese	70%1.6 mg
Phosphorus	23%289 mg
Potassium	12%363 mg
Selenium	22%12.2 µg

Sodium 0%2 mg

Zinc	15%1.67 mg
Other constituents	Quantity

Water 12.4 g

Link to USDA Database entry

†Percentages estimated using US recommendations for adults.[17]

Toxicity

In the early stages of plant growth, some sorghum species may contain levels of hydrogen cyanide, hordenine, and nitrates lethal to grazing animals.[18] Plants stressed by drought or heat can also contain toxic levels of cyanide and nitrates at later stages in growth.[19]

Nutrition

The grain is edible and nutritious. It can be eaten raw when young and milky, but has to be boiled or ground into flour when mature.[20]

Sorghum grain is 72% carbohydrates including 7% dietary fiber, 11% protein, 3% fat, and 12% water (table). In a reference amount of 100 grams (3.5 oz), sorghum grain supplies 79 calories and rich contents (20% or more of the Daily Value, DV) of several B vitamins and dietary minerals (table).

Use

Sorghum cultivation has been linked by archeological research to ancient Sudan around 6,000 to 7,000 BP.[21] One species, S. bicolor,[22] native to Africa with many cultivated forms,[23] is a common crop worldwide, used for food (in the form of grain or sorghum syrup), animal fodder, the production of alcoholic beverages, and biofuels.

In Nigeria, the pulverized red leaf-sheaths of sorghum have been used to dye leather, and in Algeria, sorghum has been used to dye wool.[24]

Polyphenols

All sorghums contain mixed polyphenols, such as phenolic acids and flavonoids.[25] Sorghum grains are one of the highest food sources of proanthocyanidins.[26]

Cultivation

Most varieties of sorghum are drought- and heat-tolerant, nitrogen-efficient,[27] and are grown particularly in arid and semi-arid regions where the grain is one of the staples for poor and rural people. These varieties are forage in many tropical regions. S. bicolor is a food crop in Africa, Central America, and South Asia, and is the fifth most common cereal crop grown in the world.[28][29]

International trade

In 2013, China began purchasing US sorghum as a complementary livestock feed to domestically grown maize. It imported around $1 billion worth per year until April 2018, when it imposed retaliatory tariffs as part of the trade war.[30] By 2020, the tariffs have been waived, and trade volumes increased again[31] before declining again as China began buying sorghum from other countries.[32] As of 2020, China is the world's largest sorghum importer, importing more than all other countries combined.