N1 PLANTS AS FOOD

Key Notes

The range of food crops

Numerous species are edible but we rely on only 20 species for 90% of our plant food and wheat, rice and maize for over half. Seeds and roots or tubers, mainly providing starch, are the staple plant foods. Leaf crops provide mainly vitamins and roughage and some seeds and fruits are rich in protein or fat.

Origin of staple crops

Wheat, oats and barley all originate in south-west Asia and were the main crops of the earliest civilizations. Rice comes from China and maize from Mexico. Ephemeral grasses have many qualities suitable for cultivation such as self-fertility, easy germination and quick growth. Certain regions of the world have been the sources of many crops. Potatoes originate in the Andes and needed much selection to be suitable for long days. Cassava is from lowland South America and other staple grain and root crops come from various tropical areas. Most of these crops have reached their present form through hybridization of related species and often polyploidy, and there are many varieties.

Other food crops

Brassicas all derive from a wild Mediterranean species and there are numerous crops from different areas. Breeding has often involved production of polyploids and, for example cultivated bananas are all sterile triploids. Some varieties such as pink grapefruit derive from somatic mutation.

Plants for flavor

Herbs are leaves deriving particularly from Lamiaceae of the Mediterranean. Spices belong to numerous families and derive from fruits, seeds, flower buds, roots or bark. They are mainly tropical and were much sought after for flavoring food in the early days of exploration in the 15th and 16th centuries.

Alcohol

All alcoholic beverages derive from plant sugar fermented by yeasts. Grapes, native to central Asia, provide sugar-rich fruit and have been fermented in a controlled way for millennia. Germinating barley is fermented for beer and barley can tolerate short summers. Numerous other plants are used.

Crops in the twentieth century

Concentration on yield led to a reduction in the number of varieties grown in the western world. With the rise in environmental consciousness more emphasis is beginning to be placed on wild sources particularly for disease resistance. Some wild crop ancestors are rare. Destruction of the ecology of agricultural soils has resulted from monocultures with high input of fertilizer and pesticide and some areas are losing their potential for agricultural production.

Related topics

Roots (C2)
The seed (D3)
Fruits (D4)
Plants in medicine (N3)
Plant cell and tissue culture (O2)
Plant genetic engineering (O3)

The range of food crops

Plants form the bulk of our food. Many plant species are edible and prior to the advent of agriculture in the meso- to neolithic period, numerous species were eaten. One of the few remaining hunter-gatherer peoples of the world, the !Kung San (bushmen) of the Kalahari, still regularly eat over 80 species of plant native to that region and use a great many more as flavors or medicines. Throughout the world over 30 000 species of plant have some edible parts, 12% of all flowering plants, and at least 7000 have been collected or grown as food at some time. In sharp contrast, a mere 20 species currently supply 90% of the world's food and just three grass species, **wheat**, **rice** and **maize**, supply about half of it. The potential for plant foods is being seriously underutilized.

The main importance of plants as food has been as providers of **starch**, the seeds of the three staple grasses being mostly starch. Other staple crops provide starchy **tubers** (swollen underground stems) such as **potatoes**, or **roots** such as **cassava** and **yams**. Leaves, stems and flowers have much less starch but supply vital vitamins and roughage, most importantly the **brassicas** (cabbage, cauliflower, sprouts, etc). Many **fruits** are sugary energy sources. Proteins and fats are present in small quantities in some of these organs although traditionally animals have been our main sources. Some seeds are rich in proteins, particularly **beans** and **pulses** connected with the fact that their root nodules have bacteria that fix nitrogen, and certain fruits, e.g. **olive**, **avocado**, are rich in fats. Oil-rich seeds have become widely planted for margarines, animal feed and non-food uses, particularly oil-seed rape (or canola), sunflowers and flax (linseed oil). Fruits and seeds come from a wide range of woody and herbaceous plants but, with occasional minor exceptions, all the vegetative parts of plants that we eat come from herbaceous plants.

Origin of staple crops

Wheat and barley are responsible for the rise of the first civilization in the Tigris/Euphrates valley, both species originating in the '**Fertile Crescent**' of mountains just north of it, ranging from northern Syria through Turkey to northern Iraq. The wild relatives of wheat, oats and barley are all ephemeral grasses of this region. Rice and maize also derive from ephemeral grasses, rice originating in **China** and maize in **Mexico**, these two species being responsible for the rise of the civilizations in these regions separately from that in the Fertile Crescent. Some of the features that characterize ephemeral grasses are those that make them good crop plants: many are self-fertile, guaranteeing seed set; they produce many seeds within a year of planting; they are characteristic of disturbed ground; they have no innate seed dormancy but can germinate as soon as conditions are favorable; in comparison with other grasses their seeds are large and rich in starch favoring rapid germination. It is likely that these plants were noticed as particularly good food sources and subsequently encouraged and cultivated. Before human intervention the seeds will have dropped from the stems to be dispersed, but, for humans, those that retained ripe seeds would have been easiest to gather for subsequent sowing so there will have been unconscious selection for seed retention.

Present-day wheat is derived from at least six wild species by multiple hybridizations. Natural, then artificial, hybridization and selection for large seeds made them the staple crops and 17 000 varieties have been produced. Modern bread wheat is hexaploid and hybridizations between the species have involved polyploidy at several stages (Topic R4). Rice and maize have fewer varieties (a few hundred), although rice derives from at least three species; maize from perhaps two.

A few particular regions of the earth, known as **Vavilov centers** (*Fig. 1*), after the Russian biologist who first described them, have supplied the most useful

Fig. 1. Centers of origin of staple crop plants (Vavilov centers): (1) Mexican highlands, (2) Northern Andes, (3) Eastern Africa, (4) East Mediterranean, (5) Fertile crescent of South-West Asia, (6) South-East Asia.

edible plants including the grain crops. Of our other staple crops, potatoes and cassava are both South American in origin and their cultivation contributed to the rise of civilizations there 6000–7000 years ago. Potatoes came from the Andes, cassava from the lowlands. In the wild, these and other root or tuber crops have poisonous alkaloids that are often bitter tasting; only years of selection of less bitter varieties have led to the crops of today. In cassava toxic alkaloids remain, since methods for fermenting and cooking it that remove the toxin are well known and the toxic varieties are more resistant to pests. The potato was imported into Europe in the 16th century and, later, North America, but it did not crop well or only very late in the long days of a temperate summer. It took nearly 200 years, until the late 18th century, to develop clones that produced adequate tubers under these conditions, and these probably came from a narrow genetic base. It rapidly became a staple, but it is prone to disease, the most important being the **potato blight**, the oomycete *Phytophthora infestans* (a fungus-like member of the Protista; Topic M4). This appeared in Europe in the 1840s with devastating consequences for the potato crop in Ireland, which particularly depended on it, leading to the famous famine. Much potato breeding and selection has been associated with disease resistance.

Other tropical staple crops come from the various regions, the millets and sorghum from Africa, dasheen or cocoyam from Asia, and different species of yams from all three continents.

Other food crops

One species of wild **cabbage**, *Brassica oleracea*, is the ancestor of all the cabbage, kale, brussels sprout, cauliflower, broccoli and kohlrabi crops. Turnips, swede and oilseed rape (canola) are closely related. The wild cabbage is widespread around the Mediterranean extending into Asia and the different cultivated types have originated in different parts of this range. Many other crops originated in this region including peas and lentils, both of which were first grown as animal feed with their nitrogen-rich foliage and later developed for human consumption. **Soya beans**, regarded as one of the world's most important developing crops because its seeds are rich in protein and oils, originated and was confined to the Far East, mainly China, until the early 20th century. There has been an enormous increase since then in the USA and elsewhere, and there have been extensive breeding programmes for its use in the short days of the tropics. Exploration of South America in the 16th to 18th centuries led to tomatoes and capsicums appearing in Europe in addition to potatoes. Cocoa, pineapples and some other tropical crops were exported from South America to other tropical colonies. South-east Asia is the native home of such pantropical crops such as bananas, sugar cane, mangoes and breadfruit, and is the center of distribution of citrus species. Apples and pears come from central Asia.

Frequently, hybridization between two or more species has resulted in varieties that are larger or more suitable for human consumption, and often polyploids. Crop **bananas** are triploid and sterile giving rise to seedless fruits that reproduce purely by clones, although all wild species are diploid. **Apples**, **pears** and **citrus fruits** are reproduced mainly by cuttings and grafts with each named variety usually being a single clone. Citrus fruits are, in addition, prone to somatic mutations, changes within the plant body that happen spontaneously without any seeds (Topic O3). One such mutation gave rise to the pink grapefruit, clones of which are now distributed in many areas.

Plants for flavor

A great variety of plants are used as flavorers in addition to those eaten as food crops. Culinary '**herbs**' are the leaves, usually dried, of various herbs and shrubs of several families, most importantly the Lamiaceae many of which are native to the Mediterranean, providing thyme, sage, mint, basil and others. The Apiaceae (umbellifers) provide parsley, caraway and aniseed. The aromatic oils and other compounds derived from these plants originate as secondary compounds, which protect the plants from herbivore attack (Topic M3) owing to their indigestibility and, frequently, bitterness. In small quantities, it is this aspect that is desirable.

Spices, prized for their strong, often 'hot' taste, derive from parts of the plant other than leaves and come from a wide range of plant families. Nearly all are tropical and spices, most importantly **black pepper**, became much sought after in the 15th century. Spices were seen as highly desirable, some as mild **preservatives**, but mainly to cover the flavor of old or decaying food and they fetched extremely high prices. Columbus's voyages to America were a by-product of the search for spices. Black pepper is native to south Asia but is now planted throughout the tropics in small quantities. Black pepper is a dried fruit, and other spicy fruits and seeds include cardamoms, allspice, nutmeg and vanilla. Spices from other plant parts include ginger deriving from a root, turmeric from a rhizome, cinnamon from bark and cloves from flower buds.

Alcohol

Alcoholic beverages are all made, at least initially, from the **anaerobic fermentation** of sugars by yeasts, unicellular ascomycete fungi. Most fruits and many nectar-rich flowers have yeasts occurring naturally, fermenting some of the sugar. Any animal may become **intoxicated** including bees feeding on alcoholic nectar which may then be unable to fly, and numerous mammals that feed on fallen fermenting fruit. The two most important crops are the **grape** with its sugar-rich fruit making wines and brandy, and **barley**, whose germinating seed is rich in sugars, the basis of most beers and whiskies. Grape vines are naturally distributed from Afghanistan to the eastern Black Sea and were taken to the eastern Mediterranean 5000 years ago. When introduced outside its native range it has sometimes hybridized with related species of each region to produce new varieties suited to the area. It is naturally dioecious but most cultivated forms are hermaphrodite, an advantage as a crop since all will produce fruits. Seedless varieties, used for consumption as grapes, appeared first by somatic mutation.

Barley originated in the fertile crescent and was one of the staple crops of early civilizations. It matures quickly which makes it adaptable to short summers and is somewhat more tolerant of salt in the soil than wheat. It was formerly an important grain staple, but today it is mainly used for alcoholic drinks and animal fodder. Other grain crops such as rice and rye are used for similar drinks and many other plants are used for making alcoholic drinks including numerous fruits, potatoes (vodka) and the pith of *Agave* (tequila) and palms (arak). Some are distilled to increase alcohol content.

Crops in the twentieth century

During the last 100 years and particularly the last 50 years there has been **intensive breeding** for increased yield in many crops (Topic O1). In the western world, the advent of apparently limitless inorganic fertilizer and a great number of pesticides, along with highly selective breeding has achieved yields unimaginable in 1900. During much of this time only the highest yielding varieties were planted and, overall, there has been a serious reduction in the number of varieties. In poorer countries, including many tropical countries, breeding has been less intensive and inorganic fertilizer is not so readily available. Crops in these countries are receiving more attention since the advent of serious famines in the 1980s and 1990s, and some genetic modification is specifically targeted at tropical countries, e.g. vitamin A in rice (Topic O3)

With increasing **mechanization** of farming, monocultures, often over large uninterrupted areas, have become widespread. All monocultures are prone to pests and diseases (Topic M3) and, in farming, these crops rely on the input of large quantities of pesticide. In the 1960s, the first evidence of environmental damage came to light in relation to persistent organochlorines such as DDT and they were banned in many countries, but are still used in others. Many other pesticides, including herbicides and fungicides, are in wide use. With the rise in environmental consciousness there has been renewed interest in wild ancestors of crops where there is often genetic variation for disease resistance. These are now being used in crop breeding programmes. Some of these wild relatives have a highly restricted distribution, the most extreme example being the closest relative of maize, *Zea perennis*, found for the first time during the 1980s on a range of less than 1 hectare in Mexico.

The high-yielding varieties grown utilize many soil nutrients and to grow them for greatest yield requires high input. One tonne of grain requires about 10 kg of nitrogen, 5 kg of phosphorus and other nutrients. At present, under intensive agriculture, most of this is replaced from inorganic sources. The combination of pesticide and fertilizer input damages the ecology severely, losing the soil structure and most of its microorganisms, beneficial as well as damaging, and this will continue to be a problem under existing agricultural regimes. In environments prone to drought there have been many problems of soil loss altogether and resulting loss of possibility for growing further crops or a natural vegetation cover, and these will undoubtedly become more widespread. Throughout the history of agriculture, using the soil too heavily for crops, particularly grain, has led to infertility. In addition, a covering of plants of any kind can affect the climate locally and some climates in dry areas have become drier overall in the depleted areas. The combination of lowered soil fertility and a drier climate has allowed deserts to spread.

N2 PLANTS FOR CONSTRUCTION

Key Notes

Timber

The lightness, strength and durability of the lignified xylem vessels that make wood have made it vitally important in the construction of buildings, furniture, ships and ornaments. It can be preserved for centuries, but fungi and bacteria can digest it in damp conditions.

Other uses of wood

Wood can be broken down into fiber to be used for paper, one of its most important current uses. Refined fibers are used as clothing fabrics, notably viscose. It was the most important fuel before fossil fuels were exploited commercially.

Wood use and the environment

Throughout history woods have been felled for pasture and agriculture and for their products. Most have not been replaced, but some regeneration of desirable species has been encouraged at the expense of less useful ones. Fuel wood has in some places been harvested by coppicing, a sustainable practice though leading eventually to reduced soil fertility. Plantations are usually conifers or eucalyptus for paper. These are usually poor in wildlife and, though the soil is retained, it is often acidified through slow leaf decay.

Fiber

Useful plant fibers are strings of sclerenchyma or collenchyma cells either from the leaves or stems of herbaceous plants or seed appendages. Many species have been used such as flax, hemp and sisal. The most important plant fiber is cotton, long unicellular seed appendages spun to fine thread. Demand for this had major historical repercussions. Nylon and 'artificial' fibers are made from oil derived from fossil plants.

Related topics

Plant communities (K2)
Mycorrhiza (M1)
Plants as food (N1)

Timber

Wood is made of elongated hollow **xylem** cells thickened with **lignin** and **cellulose** (Topic C4). Lignin in particular is strong and durable and only some fungi and bacteria are capable of digesting it. In addition, many trees secrete tannins or resinous compounds into the xylem in the **heartwood** of a tree trunk that has lost its function as water conducting cells; this acts as a preservative. Many of the vessels remain hollow and wood is light in weight considering its strength. These properties make wood excellent material for the **construction** of buildings, furniture, tools, etc, and it has been used for numerous purposes since paleolithic times. It is (or was) abundantly available across much of the habitable world. Most woods float in water and its use in building boats and ships gradually increased in importance until the early 19th century when metal ships were introduced.

The '**grain**' of some woods, formed mainly by annual growth rings (Topic C4) and its ability to be smoothed and stained have made it an important medium for sculptures and other ornaments and qualities of particular species are used to make many musical instruments, e.g. maple and pine or spruce for violins, African blackwood for clarinets. If kept dry and adequately treated, wood will last well and can last for centuries in the right conditions, although if kept permanently damp it will decay within a few months to a few decades depending on the type of wood, its size and the environment.

There is a minor but significant and constant demand for **corks** made from the spongy bark of the Mediterranean cork oak, *Quercus suber*.

Fungi and bacteria can digest the lignin and other compounds that form wood and are the organisms responsible for wood decay. All decay organisms require moisture (including the so-called 'dry-rot' fungus) and wood can be kept for centuries if it is kept dry, or treated with preservative. In the tropics termites are specialist feeders on dead wood and digest it by means of symbiotic microorganisms making it difficult to preserve wood in the wet tropics.

Other uses of wood

Wood may be broken down into fibers to make **paper** and this is now one of the largest uses for wood. Paper can be made from almost any tree species. The wood from conifers and broad-leaved trees is pulped mechanically in a water and chemical solution to extract the fibers which are then glued, pressed and bleached, the whole operation being highly commercialized. Many other fibers are suitable for paper-making and the earliest paper was made from the papyrus, *Cyperus papyrus*, from African swamps. Wood pulp is also used to make fine clothing material after chemical treatment that modifies the cellulose. One such product, sodium cellulose xanthate, is the best known fiber from wood pulp, known commercially as **viscose**.

Wood has been the most important **fuel** for burning throughout most of human history, either burned directly or first charred to **charcoal** to be used as a hotter and more efficient fuel later. Only with the mining of large quantities of coal, oil and gas since the 19th century has its importance diminished. It is well to remember that these mined fuels are all partially decayed fossil plants, including some wood in the coal, preserved by crushing and, in coal, petrifying over millions of years.

Wood use and the environment

The use of wood through history has had a profound effect on the world's plant communities. Many **forests** were destroyed to open land for pasture and agriculture, and forests had disappeared from large areas of temperate Eurasia by 0 AD. Wood used for building was usually cut without any replanting and the large quantity of wood required for ships in western Europe, mainly during the 1700s, destroyed many more. Throughout the world, forests diminished in extent through human intervention and many other wooded areas changed in character; for example, in many areas, such as much of North America, the understorey was burned to make a more open environment. Some areas of forest remained in most places for use as a source of wood. Trees were allowed to regenerate naturally and often desirable tree species were encouraged and other species removed. Useful species were increasingly planted to replace felled woods, particularly in the 18th and 19th centuries. The domination of many western European woods by the oak, *Quercus robur*, and in places beech, *Fagus sylvatica*, and the absence of the lime, *Tilia cordata*, is mainly due to human encouragement of the good timber crops. Many forests now dominated by a single species would naturally be mixed.

Fuel wood is frequently harvested on a partially sustainable basis. Many trees will regenerate new stems from a cut base and this ability has been used in **coppices** for many centuries. The understorey trees are cut on a rotational basis with a cycle of a few years or decades depending on the fertility of the site and species involved. This will periodically open the coppice to light after which it will gradually become shadier until the next cut; many plants at a woodland edge are adapted to this and have colonized coppice woodlands. Numerous small and some large wooded areas remain, particularly in northern Europe, owing to the need for coppice wood as fuel and for some construction purposes. Over centuries, soil fertility declines and it takes increasingly longer for the trees to regrow in a coppice woodland. The cork oak woods of south-western Europe have been kept for their valuable product and remain ecologically rich.

Plantations of trees have increased in the 20th century with the decline of ancient woods and with the huge demand for paper. These have largely been plantations of **conifers**, most originating in North America, in the cool temperate zones, often on acidic soils not suitable for other crops, and **eucalyptus**, originally from Australia, and other conifers in the warmer parts of the world. These plantations suffer from the problems of monoculture described in Topic N1 and can deplete the soil of nutrients. With the dense plantings, few other plants can live except in the young early stages. Many of these trees are planted in continents different from their place of origin. This has sometimes led to growth problems because of a lack of mycorrhizal infection (Topic M1) and, frequently, a limited wildlife community compared with plantations of native species. Despite this, wildlife is often more common than on open agricultural land and the soil structure and depth may be retained, though the soil may become increasingly acidic since the leaves of many trees are resistant to decay.

Fiber

Useful plant fibers come from many species, the fibers themselves consisting mainly of **sclerenchyma** cells (Topic C1), sometimes with **collenchyma** or conducting cells. Some of these have lignified walls but, for flexibility, the lignin is usually digested out to leave **cellulose** walls for the fiber. A few derive from seed appendages but most others are strands of cells within the vegetative tissue that provide support and usually have no cell contents at maturity. In a few plants the fibers are long and at least partially separate and can be used directly for clothing (e.g. the underbark of a few trees), but more frequently they must be treated before use. This usually involves soaking and beating to remove surrounding cells and sometimes treatment with chemicals. The finer fibers must then be **spun** to make long strands.

Most fibers are extracted from the **stems** of dicots or the leaves of monocots. The most important among the dicots are **flax** (*Linum* spp.) that gives us linen, used widely before cotton, and **hemp** (*Cannabis* spp.) and **jute** (*Corchorus* spp.), both of which are used mainly for rope. Among monocots, **sisal** (*Agave* spp.) and **Manila hemp** from a banana, *Musa textilis*, are still widely used. Many other species have been used and still have local uses, such as nettle species, *Urtica*, pineapple fiber, date palms, etc. With the large demand for paper some of these crops are being tested for suitability in paper manufacture.

The world's most important fiber is **cotton**, the feathery appendage of seeds of the genus *Gossypium* (Malvaceae, the mallow and hibiscus family), native to Asia and the Americas. Cotton has been used for thousands of years in India and South America. These appendages are each a single elongated cell, the longest making the finest cotton, and now most commercial cotton comes from a

South American species, *Gossypium hirsutum*. One kilogram of cotton consists of approximately 200 million seed hairs. Exploration of Asia, and later South America, introduced the fine qualities of cotton to Europe during the 15th century after which it became much sought after in Europe where there were only coarser fabrics. The huge plantations of cotton, particularly those involving slavery in the southern USA, made Liverpool the richest port of Europe and most northern English towns rich through manufacture of cotton clothing. The serious inequalities that developed between northern American states that marketed and exported cotton and southern states that grew it, was one of the major factors leading to the American civil war.

Kapok fiber derives, like cotton, from seed appendages and was used as light stuffing for mattresses and life jackets. It comes from a giant forest tree, *Ceiba pentandra*, of the Bombacaceae, related to the cotton family. **Nylon** and other 'artificial' fabrics derive from oil, itself derived from fossil plants.

N3 PLANTS IN MEDICINE

Key Notes

Ethnobotany	Ethnobotany is the science of the relationship between the chemical constituents and properties of native species of plants and their uses by indigenous peoples. As plants contain a wide range of different, biologically active secondary metabolites, the discovery of compounds new to western medicine is an important aspect of this science.
Glycosides	The cardiac glycosides or carnolides based on digitoxin and digoxin inhibit the heart Na^+/K^+-pump. Applied at appropriate dose, they stabilize the heart rhythm and are used to treat heart failure and similar conditions.
Alkaloids	Alkaloids are a wide range of compounds with many applications. The quinoline alkaloid quinine, the isoquinolines morphine and codeine, and the indole alkaloids vinblastine and vincristine, are all widely used medicinals.
Terpenes	The terpene taxol, from the bark of the Pacific yew, stabilizes microtubules and thereby inhibits cell division in tumor cells. It is therefore a potent chemotherapy agent in cancer treatment.
Related topics	Amino acid, lipid, polysaccharide and secondary product metabolism (J5); Plant cell and tissue culture (O2)

Ethnobotany

Historically, botany and medicine were closely allied subjects as most medicines were herbal, using plant materials to supply medicinally active drugs. The earliest botanic gardens were dedicated to the production of plants with medicinal properties. Human beings have used plants as medicines for millennia and there is a rapidly growing interest in identifying medicinally active plant products. This involves everything from learning about traditional medicines to the assessment of crops and native floras for the production of new medicines. The study of **ethnobotany**, the study of plant species and their uses in indigenous societies, has been inspired by awareness of rapid loss of species diversity and of the importance of plant derived drugs. Ethnobotany seeks to record the uses of plants by societies and wherever possible, to conserve those species for future use.

Medicines based on plant products include many different compounds with many different uses. The **cardiac glycosides**, based on the compound **digitonin** from foxglove (*Digitalis purpurea*) are widely used to treat heart disease. Drugs based on the plant **alkaloids**, the **opiates**, derived from the opium poppy (*Papaver somniferum*) are amongst the most effective pain-relievers known. Many **anti-cancer agents** such as **taxol** (derived from the pacific yew, *Taxus brevifolia*) and **vincristine** and **vinblastine** (derived from the periwinkle, *Vinca rosea*) are also plant products.

Plant-derived medicinal compounds are plant secondary products. The general biochemistry of the production of plant secondary products is described in Topic J5.

Glycosides

Glycosides are a very diverse group of compounds. The **cardiac glycosides** (or **cardenolides**) contain sugar residues bonded to sterols; in one example (**digitoxin**, from the foxglove *Digitalis purpurea*), the sugar residues are one glucose molecule, two digitoxose molecules and one molecule of 1-acetyl digitoxose. Digitoxose is a rare 6-carbon sugar. A second cardiac glycoside, **digoxin** is also present in the foxglove.

Cardiac glycosides are extremely toxic compounds that inhibit the heart Na^+/K^+-pump. At a suitable dose, they slow and strengthen the rhythm of the heart and are very effective in the treatment of heart failure and other heart conditions.

Alkaloids

Alkaloids are also a diverse group of compounds, all of which contain nitrogen, usually as part of a heterocyclic ring. They are synthesized from amino acids. Many alkaloids are extremely poisonous; others, including **codeine** and **morphine** are very effective **pain killers**, while others are addictive drugs (nicotine, cocaine). *Table 1* presents some of the alkaloids and their effects.

Table 1. Major types of medicinal alkaloids and their precursors

Group	Examples	Uses
Quinoline	Quinine	Anti-malarial
Isoquinoline	Morphine, codeine	Pain relief
Indole	Vinblastine, vincristine	Anti-cancer agents used in chemotherapy

Terpenes

Terpenes are synthesized either from acetyl coenzyme A (CoA) or from 3-phosphoglycerate and pyruvate and are based on the 5-carbon isoprene unit (Topic F2). Complex terpenes are generally believed to be anti-herbivory defenses in plants; however, amongst the very diverse range of terpenes are **essential oils** such as the **menthols** (used as insect repellants and in proprietry remedies for colds and coughs). The most significant medicinal terpene of recent years has been the diterpene **taxol**, isolated initially from the bark of the **Pacific yew**, *Taxus brevifiolia*. Taxol causes a blockage of cell division in tumor cells by stabilizing and polymerizing microtubules. Taxol is effective against solid tumors. Its initial discovery led to a considerable effort to secure sufficient supplies of the compound, as its production (like many plant secondary products) is limited to one tissue (the bark) of a single species. Application of plant tissue culture was less successful than attempts at organic (chemical) synthesis and taxol-based drugs are now produced by this means.

N4 Plants for other uses

Key Notes

Uses of secondary compounds	Rubber, derived from a Brazilian tree, has been highly valued and is used today in tyres. Resins and other aromatic plant products are much used in ceremonies, e.g. as incense, and many dyes come from plants. Plant oils may be used in soap and tannins from trees are used to treat leather.
Drugs	The two most important commercial drugs from plants are caffeine from coffee and tea, and nicotine from tobacco. Coffee and tea are both large cash crops from tropical countries, much prized in Europe and North America. Tobacco depletes soil nutrients quickly and was traditionally grown in new soil as the southern USA was colonized. Other drug plants are grown in scattered plantations and can fetch high prices.
Plants as symbols	Many plants have symbolic associations, often those with other useful properties. Trees that are worshipped usually have an unusual feature. Plants accompany all festivals, and some symbols, such as the olive for peace, are universal. Painting and writing about plants has influenced the conservation ethic.
Horticulture	Plants have been grown in gardens for millennia, for medicinal use, shade or recreation. Some plants have become rare from over-collecting. Ancient garden plants such as roses are much modified, with petals replacing stamens and multiple hybridizations producing a huge range of cultivars. They are propagated by cuttings and grafting onto roots of a different rose. Most plants can hybridize with related species and this has been widely used. Much propagation is by cloning from cuttings or root division. The growth form can be modified, e.g. the bonsai.

Related topics

Amino acid, lipid, polysaccharide and secondary product metabolism (J5)
Plants in medicine (N3)
Interactions between plants and animals (M3)
Plant breeding (O1)

Uses of secondary compounds

Secondary compounds within certain groups of plants (Topics J5 and M3) are among the most commercially valuable of plant products. **Rubber**, the solidified **latex** of the Brazilian tree *Hevea brasiliensis* (and occasionally other species) makes a very strong flexible solid material, particularly after treatment, and remains the main component of tyres. For many years it was the exclusive preserve of Brazil despite attempts to plant it elsewhere and fetched a high price, until in the 1870s when about 70 000 seeds were, in effect, smuggled to Kew in London under the guise of botanical specimens. Just 22 seedlings from these reached Malaysia to form the basis of the millions of hectares of rubber plantation. Rubber is tapped from the tree without doing any permanent damage and a tree can produce latex for over 20 years. Ecologically, this has the great advantage that an area remains forested, with associated benefits of soil stabilization, and it has helped to stop some Amazonian forests from being exploited.

Resins and similar **aromatic** compounds come from many flowering plants, especially trees and shrubs, and conifers. Traditionally, these have been used extensively in perfumes and were believed to have healing and magical properties. They became used for religious and other ceremonies, e.g. frankincense (*Boswellia* spp.), myrrh (*Commiphora* spp.), and other members of the Burseraceae all used as incense. Other resins made fine **varnish** and lacquer and are the base for paints, glues and some cosmetics and organic solvents such as turpentine. Their value has sometimes led to their preservation along with associated flora and fauna. Similarly, many dyes come from plants. These may derive from leaves, roots, flowers, fruits or seeds and include our most ancient dyes such as henna, derived from the leaves of the Asian *Lawsonia inermis*, and woad from *Isatis tinctoria*. Many of these became associated with ceremonies. Many soaps and detergents are made partially from plant oils, particularly the oil palm *Elaeis guineensis*, and coconut, mixed with animal tallow.

Tannins are dark phenolic compounds deriving from bark, leaves or other parts of many trees such as oaks and are traditionally used to treat leather rendering it more waterproof and keeping it flexible. Tannins in tea leaves give tea its flavor.

Drugs

Some plants contain substances that affect the nervous system, either as stimulants or depressants and these have been used for centuries, often in traditional ceremonies. As they were introduced to temperate regions, by their nature they became enormously desirable among wealthy people and at times commanded high prices. The most important of these in commercial production today are caffeine from tea and coffee, nicotine from tobacco and various medicinal drugs (Topic J5) as well as alcohol considered in Topic N1. The most commercially valuable is coffee deriving from species of *Coffea*, mainly *Coffea arabica* which comes from Ethiopia originally, but is now planted throughout the tropics. It requires adequate rainfall and is often grown in hilly districts. The markets were controlled by Arab traders until the 17th century when it was planted elsewhere and it is one of the most important export crops from South America. Tea, *Camellia sinensis*, originally from China, was also much desired. Tea plantations in India became a foundation of British occupation and high taxes on tea set by Britain on exports to North America were one of the triggers for the American war of independence.

Tobacco, *Nicotiana tabacum*, originates in the American tropics and is planted mainly in America. It is a plant requiring a fertile soil which is depleted rapidly, and tobacco production requires high inputs. It thrived on the newly cultivated soil in southern North America. Medicinal drugs such as opiates from poppies and some, mainly illegal, psychoactive drugs such as cannabis and coca derive from plants.

Plants as symbols

Plants have been used **ceremonially** since paleolithic times. Although they may have had uses as food, timber, medicine or narcotic drugs, certain individuals were frequently singled out for different uses. This has had an effect on the ecology of many regions of the world since certain plants have been preserved at the expense of others and some owe their survival to such a role. The ginkgo tree (Topic R3) has an edible seed but may owe its survival to its ceremonial role as it is unknown outside cultivation. On every continent certain plants, often trees, are traditionally worshipped, leading to the preservation of certain places as sacred groves or certain strategically positioned individual trees as sacred. Often, trees with an unusual shape are revered, such as the baobab with its swollen trunk in Africa, or the sacred banyan of India with its numerous aerial roots spreading the tree (a fig) over large areas. The properties or associations of some plants have led to their symbolic uses, for example the soothing action and antiseptic properties of rose oil probably led its importance as a symbol of all aspects of love. All festivals involve plants, and flowers are strongly associated with birth, marriage and death. The olive branch is a global symbol of peace, coming from early Mediterranean civilizations when olive oil was one of the most valuable of commodities and used as a kind of currency.

Plants feature widely in numerous paintings and writings, these having a marked influence on the way in which we perceive our landscape and to some extent have shaped the environmental conservation ethic of today.

Horticulture

For millennia in Roman, Chinese, Arabic and other civilizations, plants have been planted in pleasure gardens. Some had herbal and medicinal use or were planted for shade but some were planted purely for aesthetic reasons and certain species gained a kind of 'cult' significance, such as the plum blossom in China. During the 19th century with the huge increase in knowledge and travel, the demand for exotic plants in Europe and, to an extent, North America, became intense, leading to many plant-collecting expeditions. Some plants were over-collected, even in Europe, and became rare as a result. The interest in the rarer **ferns** of Britain at this time resulted in local extinction and the continuing rarity of a few species. Many **orchid** species are prized for their exotic blooms, but some have restricted natural ranges and are often scarce. A black market with high prices for spectacular rarities has grown, making them rarer and some in danger of extinction.

Enormous numbers of plant species are now cultivated purely for their ornamental value. Most plants are capable of **hybridizing** with related species, sometimes leading to sterility but more frequently partial sterility, so further hybridization is possible. In some groups, such as the orchids, species from several genera can be fully interfertile, making hybrids particularly easy to generate. In nature hybrids are usually at a selective disadvantage. Much reproduction for horticulture is done by cloning either through taking cuttings or dividing roots. Most **roses** and many other garden plants have **double** flowers, with many of the stamens replaced by petals; in many plants, petals probably derived initially from sterile stamens (Topic D1). Cultivated roses come from a wide range of species distributed across Eurasia from extensive breeding and hybridization through the centuries, and **cultivars**, those cultivated varieties which are marketed commercially, are mostly sterile or partially sterile multiple hybrids.

Many woody plants are reproduced by **cuttings**, small pieces of a side stem or more rarely a leaf that is separated and rooted in soil, making all plants of one cultivar genetically identical and part of one clone. Some, such as roses and fruit trees, are **grafted** onto the **rootstock** of a wild or vigorous related species because these roots are stronger and the specimen grows more vigorously. Grafting involves detaching the stem, or **scion**, around ground level and fixing it to the rootstock that has been similarly detached, following which the plants establish vascular connections. These roots may produce other stems directly, known as **suckers**, which are genetically the root not the cultivar. Occasionally, cells from the rootstock of a graft occur above ground, mixed with cells from the scion, making a **chimera**, e.g. *Laburno-cytisus*, which has brownish flowers deriving from a mix of yellow flower cells from the *Laburnum* scion and purple flower cells from the *Cytisus* stock.

A plant is flexible in its growth form and can be trained into shapes quite unlike the wild plant. Hedge trimming stimulates axillary side shoots to grow and this can be refined further to **topiary**, making a tree a recognizable shape, or training fruit trees to espaliers or fans. The most extreme example is the miniaturizing of trees to **bonsai**, developed in Japan, through elaborate root trimming and other techniques applied over a long period.

N5 Bioremediation

Key Notes

Introduction Bioremediation is the use of plants to extract heavy metals from contaminated soils and water. Success depends on the identification of species that can tolerate and accumulate toxins into shoots and leaves, which can then be removed and disposed of appropriately.

Hyperaccumulator species Some species of plants can accumulate high levels of toxins without death. Usually, they can only tolerate a single toxic ion and grow slowly. Hyperaccumulation is thought to confer disease and pathogen resistance.

Bioremediation Bioremediation of soils may be through the use of hyperaccumulators, genetic modification of crop species or by the use of chemical chelators. Decontamination of water can be carried out by rhizofiltration using species with high transpiration rates and by use of aquatic plants. In some instances (e.g. selenium, mercury) volatilization of the toxin to the atmosphere will also contribute to decontamination.

Related topics

Stress avoidance and adaptation (G5)
Movement of nutrient ions across membranes (I3)
Uptake of mineral nutrients by plants (I4)
Plant genetic engineering (O3)

Introduction

Many soils are contaminated with toxic pollutants. These may be from atmospheric deposition, mine spoil, sewage sludge or contaminated ground water, or may be natural deposits of toxic ions. Some species of plant tolerate high levels of soil toxins and **phytoremediation** and **bio-mining** (the use of plants to extract minerals) has developed from the additional observation that some species accumulate toxic elements to a high level. Such species, which may accumulate more than 100 times the amounts of a toxin than other plants, are called **hyperaccumulators**. However, bioremediation not only depends on the use of natural hyperaccumulators, as other species may be induced to take up high levels of soil toxins either by adding **chelating agents** (chemicals which bind to the toxin) to the soil or by genetic modification.

Toxic ions which are found in soils and may be suitable for phytoremediation are cadmium, cobalt, copper, lead, manganese, nickel, selenium and zinc.

Hyperaccumulator species

Hyperaccumulator species have been identified for most of the toxic ions found in soils, including radionuclides (*Table 1*). To be used successfully for bioremediation, hyperaccumulators must accumulate the toxic ion in their leaves and shoots, as removal of roots from soil is likely to be impracticable. In most instances, hyperaccumulators only grow slowly; it is assumed that the main selective advantage gained by hyperaccumulation is in deterring predators and pathogens, as tissues containing heavy metals are unpalatable and poisonous.

Table 1. Examples of hyperaccumulator species for various toxic ions

Metal	Number of hyperaccumulators known	Key example species	Amounts accumulated
Cadmium (Cd)	1	*Thlaspi caerulescens*	>100 $\mu g\ g^{-1}$ of dry weight
Cobalt (Co)	26	*Haumaniastrum katangense*	>1% dry weight
Copper (Cu)	24	*Aeollanthus biformifolius*	>1% dry weight
Manganese (Mn)	11	*Alyxia rubricaulis*	>1% dry weight
Nickel (Ni)	290	*Streptanthus polygaloides*	3–8 $mg\ g^{-1}$ of dry weight
Selenium (Se)	19	*Brassica juncea*	1–10 $mg\ g^{-1}$ of dry weight
Thallium (Tl)	1	*Iberis intermedia*	2 $mg\ g^{-1}$ of dry weight
Zinc (Zn)	16	*Thlaspi calaminare*	>1% dry weight
Zn+Cd	1	*Thlaspi caerulescens*	>100 $\mu g\ g^{-1}$ of dry weight
Cu+Co	1	*Haumaniastrum katangense*	>1% dry weight

The fact that they only accumulate small amounts of biomass means that the total amount of an ion extracted from the soil may be small. As most hyperaccumulators can only tolerate one toxic ion, this means that they may not be effective where a soil contains several contaminants. Examples of hyperaccumulator species are shown in *Table 1*.

Bioremediation

Bioremediation involves the use of plants to remove toxins from soils or water. Bioremediation can be used to decontaminate soil by growing plants which accumulate the toxin and are then harvested and removed. Water can be decontaminated by **rhizofiltration**, in which contaminated water is passed through the roots of plants that extract the toxins and by the use of aquatic plants which are harvested and destroyed.

The species listed in *Table 1* have potential for bioremediation of soils; however, because of the slow growth rates and poor yields, other alternatives are being explored. These include **genetically modifying plants** (e.g. arabidopsis; Topic E1) and the use of **chelating agents** to mobilize soil toxins and reduce their toxicity to the accumulator plant. Arabidopsis has been successfully modified to express mercuric ion reductase (which converts toxic Hg^{2+} to Hg^0 which is volatilized to the atmosphere). Experiments using a chelating agent have shown that a crop of maize can accumulate >200 μg of mercury per gram of shoot dry weight from contaminated soil. Volatilization to the atmosphere as a result of uptake by plants is very significant for selenium. *Brassica juncea* (a wild mustard) accumulates up to 10 $mg\ g^{-1}$ (dry weight) of selenate; it also releases large quantities of dimethyl selenate to the atmosphere resulting in 25–40% loss to the air.

Several species have been indicated as useful for **rhizofiltration**. The best are plants with extensive root systems and which have high transpiration rates. Hybrid poplars achieved a complete removal of zinc from a solution of 800 μg ml^{-1} in 4 h and willows (*Salix* sp.), *Brassica juncea*, sunflower (*Helianthus anuus*) and reeds (*Phragmites*) all show potential. Overall, plants like this offer a potentially effective method for the decontamination of effluent, one with negligible energy input and at low cost.

Experiments with water hyacinth (*Eichhornia crassipes*) show uptake of up to Cd, Co, Pb, Hg, Ni and Au from contaminated fresh water, with a total biomass production of 600 kg Ha^{-1} day^{-1}. Seaweeds can be used to accumulate iodine from sea water and as indicators of local metal contamination.