

CROP PLANTS

Key Objectives

- To be able to describe and explain structural features of a named, wind pollinated plant
- To compare the genetic outcomes of self and cross-pollination
- To be able to describe the structure of the fruit in maize and explain the function of the endosperm
- To be able to explain the significance of the inclusion of the grains of cereal crops in the human diet
- To be able to explain how the leaves of C₄ plants (such as maize or sorghum) are adapted for high rates of carbon fixation at high temperatures
- To be able to explain how sorghum is adapted to survive in arid environments
- To be able to explain how rice is adapted to survive with its roots submerged in water
- To be able to explain various examples of how crop plants can be improved. :
 - Hybridisation to produce polyploids in wheat
 - Inbreeding and hybridisation to produce vigorous, uniform maize
 - Genetic manipulation to enhance the vitamin A content of rice

Key Definitions

- *Pollination* - the transfer of pollen from an anther to a stigma.

Self-pollination is when the transfer occurs in the same flower or from one flower to another on the same plant.

Cross-pollination is when the transfer is from one plant to another.

- *Xerophyte* – a plant which has a number of structural and physiological features which allow it to live successfully in areas of low water supply i.e. arid environments.
- *Hybrid* – a plant which is the result of interbreeding between two different species.
- *Polyploid* – a plant which has more than two sets of chromosomes.

Key Ideas

The structural features of a wind pollinated plant

Wind pollinated plants have flowers with a number of structural features, which distinguish them from insect pollinated plants. These include:

- Flowers are borne at the end of long stalks, held well above the foliage. In some cases, the flowers appear before the leaves.
- Small, inconspicuous petals – often green in colour. Petals may be absent altogether.
- Stigmas are large, branched and feathery – and held outside the flower.
- Stamens are pendulous and also hang outside the flower.
- Anthers are versatile i.e. they are attached at the midpoint, so they will swing freely in the wind.
- Pollen grains are relatively light and small.
- Pollen grains are produced in very large quantities.
- Absence of nectaries.
- Absence of scent.

<http://en.wikipedia.org/wiki/Anemophily> <http://florawww.eeb.uconn.edu/collections/pollination.html>

The genetic outcomes of self and cross pollination

Assuming that pollination results in successful fertilisation, the main genetic outcomes will be as follows:

self pollination	cross pollination
decreased genetic variation / increased genetic uniformity	increased genetic variation / decreased genetic uniformity
increased homozygosity / decreased heterozygosity	increased heterozygosity / decreased homozygosity
harmful recessive characteristics more likely to be expressed	harmful recessive characteristics less likely to be expressed
reduction in gene pool	maintenance of gene pool
inbreeding depression reduces fitness	gives hybrid vigour (= heterosis = outbreeding enhancement), so fitness maintained

All of these outcomes mean that populations which result largely from cross pollination are phenotypically more variable, which gives them more evolutionary potential and means that they are better able to adapt to changes in the habitat or environment.

<http://en.wikipedia.org/wiki/Heterosis> http://en.wikipedia.org/wiki/Inbreeding_depression

The structure of the fruit in maize and the function of the endosperm

The individual fruit of maize is a dry fruit (known, botanically, as a *caryopsis*) and contains a single seed.

The seed contains two structures – a *germ*, from which a new plant will develop and an *endosperm*, a store of nutrients which will be made available to the germinating seedling until it has established sufficient leaf area to photosynthesise.

The germ consists of a miniature plant axis to which are attached around five embryonic leaves and a radicle, from which the root will develop. The germ is the source of maize 'vegetable oil'.

The endosperm takes up about two thirds of the volume of the seed and accounts for around 86% of its dry weight. The principal component of the endosperm is starch, together with about 10% protein (gluten). Its function is to provide the nutrition required by the germinating seedling – though it is also the basis of the nutritional value of maize. Whole, ground maize meal has an energetic value of around 1500 kJ per 100g.

<http://www.science.siu.edu/plant-biology/PLB117/Nickrent.Lecs/Fruits.html>, click on 0535.jpg for an image of a corn grain. <http://quorumsensing.ifas.ufl.edu/HCS200/Seed.html> has protocols for investigating a number of fruits including a maize caryopsis.

The significance of the inclusion of cereal grains in the human diet

Cereal grains are a major component of the human diet in many parts of the world. In terms of nutritional value, most cereal grains are similar though they do vary in the levels of some nutrients, such as vitamins and minerals. The final nutritional value will also depend greatly on the amount of processing involved.

The nutritional value of cereal grains include:

- Carbohydrates (mainly starch) are a major component of cereals – usually 70 to 80%. Hence, they are a very important source of energy.
- Source of protein. Most cereals have a protein content of between 6 and 14%. In general, millets, rice and maize are at the low end of the protein range, rye and barley are intermediate and wheat and oats are high.
The main problem with regard to the provision of protein is that cereals do not always provide a balance of amino acids. They are especially low in lysine, an essential amino acid, which means that other sources of this need to be included in a balanced diet.
- All cereal grains are low in fat. This is usually 2 – 4%, though oats are an exception with 7.5%. However, they are high in essential fatty acids, such as linoleic acid.
Most of the fat is found in the germ of the grain.
- Vitamins – all cereals provide a good source of the B group vitamins (thiamin, riboflavin, niacin, B6, folic acid, biotin and pantothenic acid) and the fat soluble vitamin E. However, they are deficient in vitamins A, D and C.
- Minerals – a range of minerals are found in most cereals. These include potassium, calcium, magnesium, phosphorus, iron and zinc.
- Fibre – cereals are an excellent source of dietary fibre. Wholegrain meal or flour will contain much more fibre than grains which have been processed and refined.

<http://www.food.rdg.ac.uk/online/fs552/Cereals.ppt> reviews the nutritional importance of some key cereals.
<http://en.wikipedia.org/wiki/Cereal>

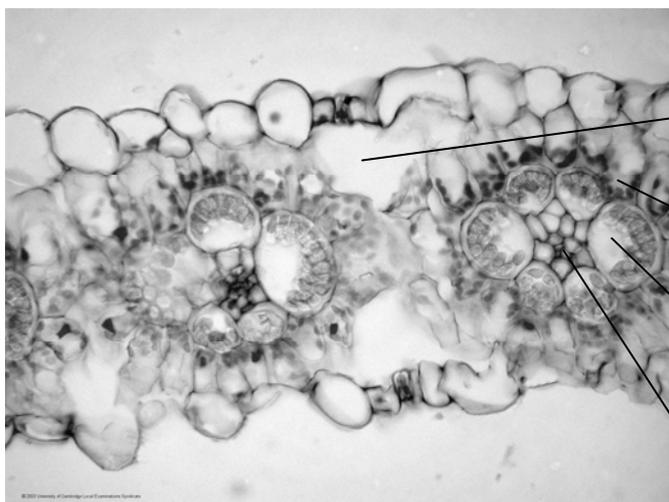
Adaptations of the leaves in C₄ plants

Conditions of high temperature and high light intensity will increase the rate of photorespiration in plants. In photorespiration, the enzyme ribulose biphosphate carboxylase (Rubisco) acts as the catalyst for the combination of oxygen with RuBP, instead of carbon dioxide. This results in an overall intake of oxygen and output of carbon dioxide and means that less RuBP is available for carbon dioxide fixation.

Conditions which promote photorespiration are found in the tropics. Tropical grasses have a leaf structure which allows them to avoid photorespiration. Such plants are referred to as C₄ plants. Some of the most productive crop plants in the world are C₄ plants - for example, sugarcane and maize.

The structural features of the leaves which distinguish C₄ plants are as follows :

- Around the vascular bundles are arranged a group of cells known as *bundle sheath cells*. These cells contain RuBP and Rubisco, but have no direct contact with the air and, therefore, are not exposed to high concentrations of oxygen.
- Around the bundle sheath cells is another ring of *mesophyll cells* – these are in contact with air spaces, but have no air spaces between them, ensuring that no oxygen reaches the bundle sheath cells.
- The mesophyll cells contain an enzyme called *PEP carboxylase*, which catalyses the combination of carbon dioxide with a compound called phosphoenolpruvate or PEP. This results in the formation of oxaloacetate.
- This oxaloacetate is then converted to malate, which is passed on to the bundle sheath cells, where carbon dioxide is removed from the malate and combined with RuBP in the usual way. The Calvin cycle then proceeds as normal.



maize leaf t.s, high-power (x500)

air spaces well away from bundle sheath cells, beneath stomata

mesophyll cells with chloroplasts, but no air spaces between them

bundle sheath cells, Rubisco is isolated from oxygen in the air so that photorespiration is minimised

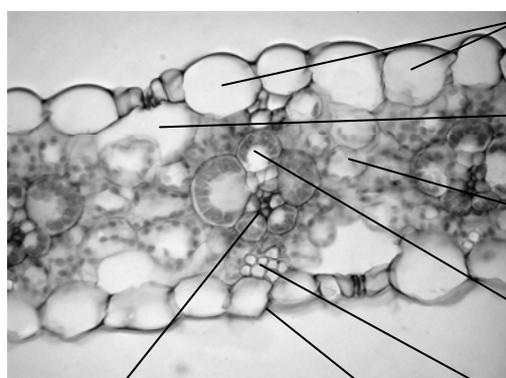
vascular bundle containing xylem to supply water and phloem to translocate sucrose away from the leaf

How sorghum is adapted to survive in arid environments

Sorghum is the fifth most important cereal crop in the world. It is of particular importance in areas of low rainfall – it is able to grow successfully in areas of low water supply and shows many of the characteristics associated with *xerophytes* (plants adapted to living in arid conditions). These include :

- A very dense root system – both widespread and deep, allowing an efficient uptake of whatever water is available.
- The leaves are covered with a thick, waxy cuticle especially on the lower surface – reduces the evaporation of water from the surface of the leaves.
- Specialised *motor cells* (bulliform cells) on the upper-side of the leaves and strengthening tissue (sclerenchyma) below the vascular bundles, which cause the leaves to roll inwards when water is in short supply, hiding away half of the stomata. This allows the build up of water vapour, reducing the difference between the water potential inside the leaf, again reducing the diffusion of water vapour from the leaves.
- The number of stomata is low and the air spaces inside the leaf are small. They are only found well away from the vascular tissues, increasing the distance that the water has to diffuse before it is lost from the leaf.
- Like maize, it is a C4 plant, so, as long as there is sufficient water, sorghum can continue to photosynthesise even when it is very hot and sunny.

sorghum leaf t.s, high-power (x500)



motor cells (bulliform cells) which cause the leaf to roll up when they lose turgor, as a result of drought

small air spaces well away from bundle sheath cells, close to the few stomata

mesophyll cells with chloroplasts, but no air spaces between them

bundle sheath cells, Rubisco is isolated from oxygen in the air so that photorespiration is minimised

vascular bundle containing xylem to supply water and phloem to translocate sucrose away from the leaf

strengthening tissue (sclerenchyma) to support leaf blade when it wilts and rolls up

thick cuticle on lower surface of leaf

How rice is adapted to grow with its roots submerged in water

Key varieties of rice may be described as ‘swamp plants’. As crop plant, it is often grown partly submerged in paddy fields. Fields are flooded, then ploughed and the young rice plants are planted in the resulting mud. Oxygen levels in the mud fall very rapidly as the oxygen is used up by respiration of bacteria in the mud – and levels remain very low in the flooded paddy fields since oxygen can only diffuse very slowly through the water.

Rice plants have a number of adaptations which allow them to grow successfully in these conditions of low oxygen availability:

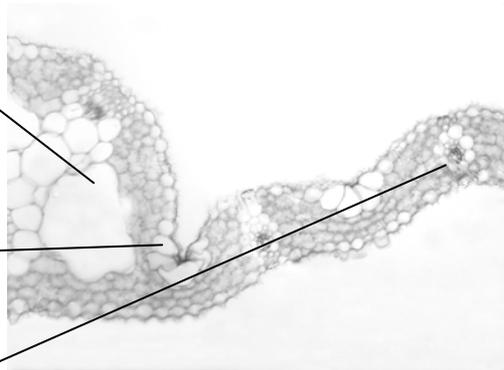
- The stems and leaves possess very large air spaces, running the length of the stem – these allow oxygen to get through to the roots from the air.
- The roots are very shallow – this allows them some access to the higher levels of oxygen in the surface water.
- When oxygen concentrations fall to very low levels, the roots are able to respire anaerobically. This results in the production of alcohol, which would normally be toxic. However, rice root cells show an unusually high tolerance to alcohol - they are able to produce high levels of the enzyme *alcohol dehydrogenase*.

rice leaf t.s, medium-power (x200)

air spaces that run right down through the leaves and stems into the roots

motor cells (bulliform cells) which cause the leaf to roll up when they lose turgor, so that the rice is protected in case the fields dry out

C4 organisation so Rubisco is isolated from oxygen in the air so that photorespiration is minimised in hot conditions



<http://www-plb.ucdavis.edu/labs/rost/Rice/Roots/rtgro.html> <http://www.biologymad.com/resources/Crop%20Plants.pps>

Producing polyploids in wheat through hybridisation

Modern bread wheat (*Triticum aestivum*) is a hexaploid plant i.e. it possesses six sets of chromosomes (6n). It is the result of the hybridisation of several wild species of grasses. These species are closely related, so their chromosome numbers and structures are similar but not identical. Such inter-specific hybrids contain one set of chromosomes from one parent species and a second, non-homologous, set of chromosomes from the other, different, parent species. When they attempt to undergo meiosis, it fails because the chromosomes cannot line up with their homologous partner chromosome. Such sterile hybrids could only reproduce asexually.

However, in all organisms, including these sterile hybrids, occasional errors occur in the cell division during the formation of gametes, so that some gametes are diploid (2n) rather than haploid (n). The chromosome number of such gametes is doubled as a result of rare failures of the chromosomes to separate during a mitotic division (termed non-disjunction) before or during gamete formation. If such diploid (2n) male gametes fuse with diploid (2n) female gametes, for example after self-pollination, the resulting offspring is tetraploid (4n). The tetraploid plant contains two sets of chromosomes from each of the original parent species, so there *are* homologous pairs of chromosomes. Meiosis can occur normally as there are now homologous

pairs of chromosomes, and so a new, fertile, species of plant has been instantly formed.

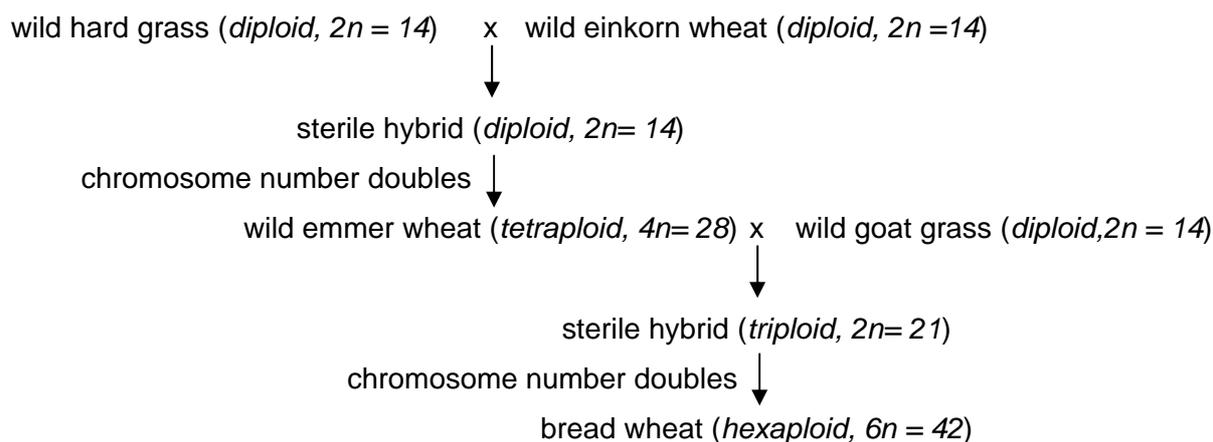
The doubling of the chromosome number appears to have occurred twice during the evolution of modern wheat – resulting in the formation of fertile polyploids from previously sterile hybrids. It is thought that the first doubling of the chromosome number occurred about 0.5 million years ago and the second about 9,000 years ago.

The formation of polyploids has been important in the evolution of plant species – though less important in animals as animal polyploids are often not viable.

It is now possible to induce the formation of polyploids by preventing spindle formation, using chemicals such as colchicine.

Among plant species, polyploids are generally more hardy and higher yielding than their parent species – making them important food crops. The ancestors of wheat are small, not very robust, and produce small ears of small seeds, in contrast to modern hexaploid (6n) wheat.

The following diagram summarises the evolution of modern bread wheat :



<http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/P/Polyploidy.html> <http://en.wikipedia.org/wiki/Polyploidy>

Producing vigorous, uniform maize through inbreeding and hybridisation

Maize is one of the most widely grown crop plants. Growing conditions will vary considerably in different parts of the world (soil type, prevailing temperature, rainfall etc) – hence, through selection, inbreeding and hybridisation, growers have been able to produce varieties that grow vigorously (and are, therefore, high yielding) and uniformly under the prevailing conditions. Assuming that conditions remain similar year after year, farmers can continue to grow the same variety and expect to obtain a similar crop.

The characteristics which are desirable in a crop plant such as maize are:

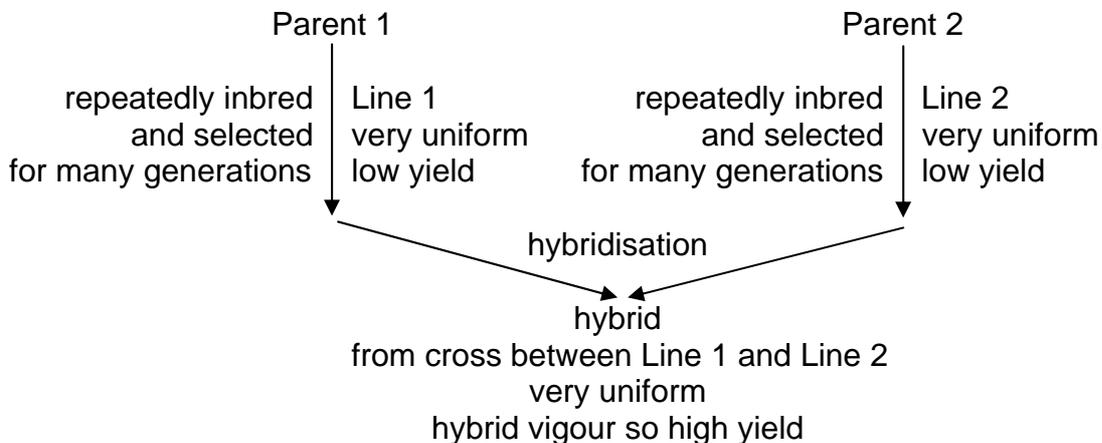
- high yielding
- disease resistant

- good quality in terms of desirability to market
- vigorous growth under the prevailing conditions.
- plants all grow to a similar height (making harvesting easier)
- crops are all ready to harvest at the same time

Given the normal range of genetic and phenotypic variation in a population of plants, when maize was first cultivated, most plants would only show some of these characteristics. Plants which did show some of the desirable characteristics would be selected and self pollinated. When pollen has been transferred to the stigma, a muslin bag is placed around the flower to ensure that pollen from other plants does not reach the stigma. If this is repeated for many generations, plants will be produced which are homozygous for the desired characteristics.

Maize is a natural outbreeder and it is not very tolerant of inbreeding – such inbreeding can lead to a loss of vigour and fertility, as well as a reduction in size and yield. This is known as *inbreeding depression*. However, the inbred maize has very little variation, with every plant having the same alleles of every gene.

However, if two inbred lines are crossed, it will produce a hybrid that has a greater yield and is more vigorous than either of the parental lines. This is known as *hybrid vigour*. This hybrid is heterozygous for most genes, so deleterious recessive alleles are hidden, but at the same time it inherits the lack of variability from its parents. Such single cross hybridisation has been used for selective breeding since the early 1960's to double the yield (from 4 → 8 tonnes per hectare) and to breed uniform, high yielding maize.



About 100 years ago maize breeding, the first attempts at using inbreeding for maize breeding began. Initially the inbred lines were so low yielding that too little seed was available for the market. For this reason, double crosses were used. Two inbred lines were crossed to create a hybrid, which was then crossed with an unrelated hybrid from two other inbred lines. The resulting double cross hybrid was rather more variable, but more seed was made available. Double cross hybridisation as a selective breeding tool increased maize yields between 1920 and 1960 from 1.5 to 4 tonnes per hectare.

In order to carry out the inbreeding or to carry out a cross to form a hybrid, pollen from a specific male parent must be used to fertilise a specific female parent. To

ensure that the cross intended is the only one that occurs, anthers are removed from some flowers which will form the female parent. Pollen is transferred from the anthers of the male parent flowers to the stigmas of the flowers without anthers. Muslin bags are then placed around the fertilised flowers to prevent pollination by any other pollen.

Selection for measurable characteristics such as yield is done by measuring the characteristic and choosing from breeding those plants that express it most strongly, e.g. having the highest yield. Selection for disease or pest resistance is done by exposing the plants to the disease or pest, which kills any that are not resistant

Seeds which result from such breeding are grown and plants showing the desirable characteristics are bred again – the process can be repeated for many generations.

http://res2.agr.ca/CRECO/zea/zea01_e.htm <http://www2.mpiz-koeln.mpg.de/pr/garten/schau/ZeamaysL./Maize.html>
<http://www.genetics.org/cgi/content/full/148/3/923> <http://maizeandgenetics.tamu.edu/hybridvigor.htm>
http://www.pioneer.com/usa/research/pipeline/articles/improving_products.htm

Enhancing the vitamin A content of rice through genetic manipulation

The green parts of rice plants contain beta-carotene, which is a vital precursor of vitamin A. However, there is no beta-carotene in the grains and in those parts of the world where rice is the principal staple food, small children are very prone to Vitamin A deficiency.

Vitamin A is essential for the operation of the body's immune system and a deficiency causes increased risk of infection, night-blindness and, in some cases, total blindness. Over 1 million children die every year as a result of vitamin A deficiency.

A genetically-modified strain of rice has now been produced which stores significant levels of beta-carotene in the grains. This strain is known as 'golden rice' and contains genes which have been transferred from the daffodil and a bacterium. It is suggested that this genetically modified rice contains sufficient beta-carotene to satisfy daily vitamin A requirements with 300 g of cooked rice.

The method generally used to transfer genes into plant cells is to incorporate the genes into a bacterial plasmid and use bacteria such as *Agrobacterium tumefaciens* to carry the genes into the plant cells. However, in the case of rice (and other crop plants, such as maize) a method has been developed whereby the genes are delivered directly into the cells using small μm -sized tungsten or gold bullets coated with DNA. The bullets are fired from a device that works similar to a shotgun. This delivery device is known as a 'gene gun' and is now a common method used in the genetic transformation of rice.

When this strain of golden rice was first developed, it was thought by some that it would provide an instant solution to the problems of vitamin A deficiency. However, not everyone believes it is the best answer. Given the controversy and concern about GM crops, it still has not been grown in field trials in Asia – and many agricultural experts and environmental groups believe the solution is not to go down the route of

GM crops, but rather to aim for a more balance diet, which would include more fresh vegetables, which have a naturally high content of beta-carotene.

Information about golden rice on the internet tends to be a bit inaccessible and difficult to use. There's some interesting evaluative material in <http://www.foe.org/safefood/rice.html> that might prove useful. Another version of the rice is described at <http://www.eufic.org/gb/food/pag/food17/food174.htm> and <http://www.agbioworld.org/biotech-info/topics/goldenrice/gmgolden.html> in which far more carotene is produced.

Crop Plants Self Assessment Questions

SAQ 1 State **four** features associated with wind-pollinated flowers.

- 1
- 2
- 3
- 4

SAQ 2 Compare the genetic outcomes of self pollination with cross pollination.

self	cross

SAQ 3 Discuss the benefits of including cereal grains in the human diet.

SAQ 4 With reference to photosynthesis:

- (a) State the problems faced by plants growing in conditions of high temperature and light intensity.
- (b) Explain how C₄ plants overcome these problems.

SAQ 5 Sorghum is an example of a xerophyte. Describe the features of Sorghum which allow it to grow successfully in arid environments.

SAQ 6 Outline how bread wheat, which is hexaploid, has evolved from two original diploid grasses.

SAQ 7 Explain how inbreeding and hybridisation have been used to develop vigorous, uniform maize.

SAQ 8 With reference to rice,

- (a) Explain why many children show a deficiency of Vitamin A in areas where rice is a principal component of the diet.

- (b) Discuss how rice may be genetically manipulated to help overcome this Vitamin A deficiency.