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## Sugarbeet, and other cultivated beets

*Beta vulgaris* L. (Chenopodiaceae)

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Over the past 30 years the damson-hop aphid and red spider mites have developed high levels of resistance to most of the pesticides used against them, and similar problems are being encountered with control of the mildew diseases. Very good progress has been made with developing cultivars resistant to downy mildew, powdery mildew and *Verticillium* wilt, and efforts are now being concentrated on resistance to aphid and spider mite damage.

### Prospects

Breeding for resistance to pests and diseases has been stimulated by concern over pesticide residues as well as by difficulties in achieving adequate chemical control. Plants with considerable resistance to attack by the damson-hop aphid have been discovered and there are very good prospects that these, combined with measures to increase the role of predators, will go a long way to reducing the need for insecticide applications. There are indications that this will, at the same time, help with the control of spider mites. With high levels of disease resistance already achieved there could soon be a major reduction in the use of chemical controls.

Conventional hop-growing techniques require a high labour input and this could be greatly reduced by developing dwarf cultivars that can be grown on a low trellis and harvested by a mobile picker. A dwarf plant was first recorded at Wye in 1977 and a breeding programme carried on since then, combined with the development of a mechanical harvester, offers good hopes of a major development in hop-growing methods (Gunn and Darby, 1987).

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### Introduction

The cultivated sugarbeet is the most important cultigen within the species *Beta vulgaris*, which has only been grown as a commercial crop since the beginning of the nineteenth century. Before that, crystalline sugar, a scarce luxury in the Western world, could only be obtained from sugar cane. Now, nearly half the world production of sucrose comes from sugarbeet. The crop is mostly grown in temperate regions, particularly in Europe, the former Soviet Union and North America, but it is also grown in subtropical conditions under irrigation. The former Soviet Union is by far the biggest producer, considerably ahead of Germany, the USA and 30 other countries throughout the world. Sucrose is accumulated in the swollen taproot plus hypocotyl of the biennial beet plant. Plants are topped at harvest and the tops may be used as feed for livestock. The sucrose is extracted from the beet in factories, using a process similar to that used for sugar cane, and after extraction, the remaining pulp is increasingly being sold commercially as an animal feed (Smith, 1987).

The other forms of cultivated beets are less important agriculturally. The earliest forms of beets to be cultivated were the leaf beets and chards which are used as garden vegetables and do not possess a swollen taproot. Leaf beets are used in the same way as spinach, while chards, with their thickened, fleshy leaf petioles, have a similar use to asparagus. Garden beets (beetroots, table beets and red beets) all possess swollen taproots which are highly diverse in colour, shape and size. Forage beets (including mangolds and mangel-wurzels) possess very large swollen roots of various shapes and colours, which have been developed for the use of the root as cattle feed.

### Cytotaxonomic background

*Beta* is an Old World genus mainly confined to Europe and the Near East. The genus is divided into four sections: Beta, Patellares, Corollinae and Nanae. The section *Beta* has the widest distribution and extends through Asia into China. The Corollinae species occupy eastern parts of Europe and the Near East, while Patellares is confined to the South-West, particularly the Canary Islands. Section Nanae is solely confined to three mountains in Greece. Cultivated beets are all derived from the section Beta, although useful characters, such as disease resistance, occur in sections Patellares and Corollinae, and attempts are being made to incorporate these characters into sugarbeet (van Geyt *et al.*, 1990). Crossing is easily accomplished between all forms within the section Beta, but crossing between species of the different sections is more difficult. Systems of classification have been published which are complex and in some cases difficult to apply. Broadly, however, the section Beta comprises the following:

<i>Beta vulgaris</i>	subsp. <i>vulgaris</i>	sugarbeet
		garden beet
		fodder beet
	subsp. <i>cicla</i>	leaf beet
		spinach beet
		Swiss Chard
	subsp. <i>maritima</i>	wild sea beet
	subsp. <i>adanensis</i>	
	subsp. <i>trojana</i>	
	subsp. <i>macrocarpa</i>	

*Beta patula*

*Beta atriplicifolia*

These taxa have been variously accorded specific or subspecific rank by different authors.

Diploid chromosome numbers within the genus are  $2n = 2x = 18$  (e.g. *B. vulgaris*),  $2n = 4x = 36$  (e.g. *B. corolliflora*, *B. patellaris*),  $2n = 6x = 54$  (e.g. *B. trigyna*). Spontaneous chromosome doubling can result in the occurrence of autotetraploid individuals, and there are indications of allotetraploidy in section *Patellares*.

### Early history

The use of beet certainly precedes Greek and Roman times, when, as in the early Orient, the leaves were

used medicinally and as potherbs (Ford-Lloyd and Williams, 1975). Early descriptions of leaf beets and chards are given by Aristotle and Theophrastus, and in some more detail by Eudemus in the second century AD, and a recent account of the existing diversity is given by Frese (1991). No indications of the existence of a fleshy swollen root can be discerned for certain until the sixteenth century, when varied descriptions of 'beetroots' were given. It is likely that the initial introduction of quite homogeneous turnip-rooted Roman red beet into northern Europe took place in the sixteenth century. Many varied forms were then described by sixteenth- and seventeenth-century herbalists in Europe, as a result of uncontrolled hybridization with leaf beets. The first use of beet for feeding cattle was described in 1787 by the Abbé de Commerell who referred to a mangel (or runkelrube) originating in the Rhineland in 1750. By the varied descriptions it can be inferred that it originated from crossing between large-rooted garden beets and chards. In fact the account by de Commerell is a clear description of segregating progeny following hybridization between a large rooted red garden beet and a white form of leaf beet (Ford-Lloyd, 1986). There is even more definite evidence for the origin of the sugarbeet itself. Olivier de Serres (1539-1619) referred to a syrup, made in France from dark red beets. Marggraf (1707-82) identified the sweet substance contained in beets as being the same as cane sugar, and this discovery caused Archard (1753-1821), a student of Marggraf, to grow beets for sugar production first near Berlin and then in Silesia where the first sugar factory was set up in 1802. It is fairly clear from the descriptions given that, once again, the beets from which selection of sugarbeets was made were white-rooted progeny derived from crossing pigmented garden beets with chards. These selections were referred to as the 'Weisse Schlesische Rube'. This mother of sugarbeet had a sugar content of up to about 6 per cent, and was introduced into France in 1775. In 1811, Napoleon actually decreed that beet should be grown for sugar and schools were set up for its study. This may have been prompted by the disruption of the supply to France of cane sugar from the West Indies, caused by British naval blockades of continental ports. Alternatively, it may have been an attempt by the French to damage British trade (in cane sugar) by deliberately developing a domestic sugar industry. On several occasions since,

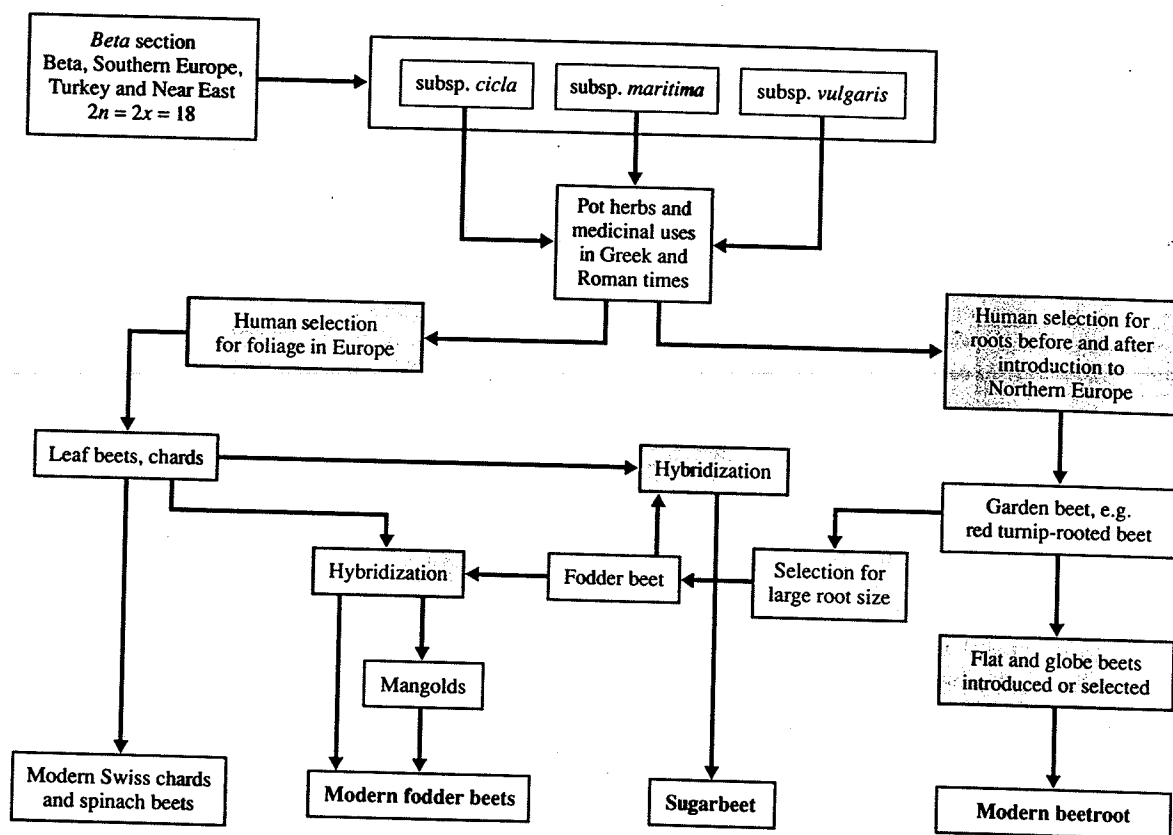


Fig. 11.1 Evolution of cultivated *Beta vulgaris*.

and as recently as 1969, resynthesis of sugarbeet from fodder beet and chard crosses has been successful (Fischer, 1989). The evolution of cultivated *Beta vulgaris* is summarized in Fig. 11.1.

**Recent history**

Mass selection for increased sugar content began in 1786, and was continued by the von Kopp family until about 1830 to increase the percentage sucrose from 6 to 9 per cent. Rapid advances were made in breeding for sugar content, facilitated by the polarimetric methods of estimating sugar. The trend was encouraged in Germany and later in other countries, by the imposition of excise duty levied on root weight. Government support was essential for the development of the sugarbeet industry both in Europe

and later in the USA where the first sugarbeet factory was set up in California in 1870. Continued selection for sucrose content has now yielded cultivars which average over 18 per cent sucrose.

Sugarbeet is outbreeding, and varieties grown in the first half of the present century were multilines based on 20–30 parental stocks. The parents were maintained by sib mating, with mass selection at each generation for root size and sucrose content. Pollination in the final generation was random, with all plants producing pollen and seed. The commercial crop consisted of 95–97 per cent interline hybrids.

Exploitation of polyploidy began in the late 1930s with the discovery that triploid sugarbeet hybrids could out-yield both diploid and tetraploid parents. Anisoploid varieties are mixtures of diploid, triploid and tetraploid plants produced by interpollination of diploid and tetraploid parental populations. These

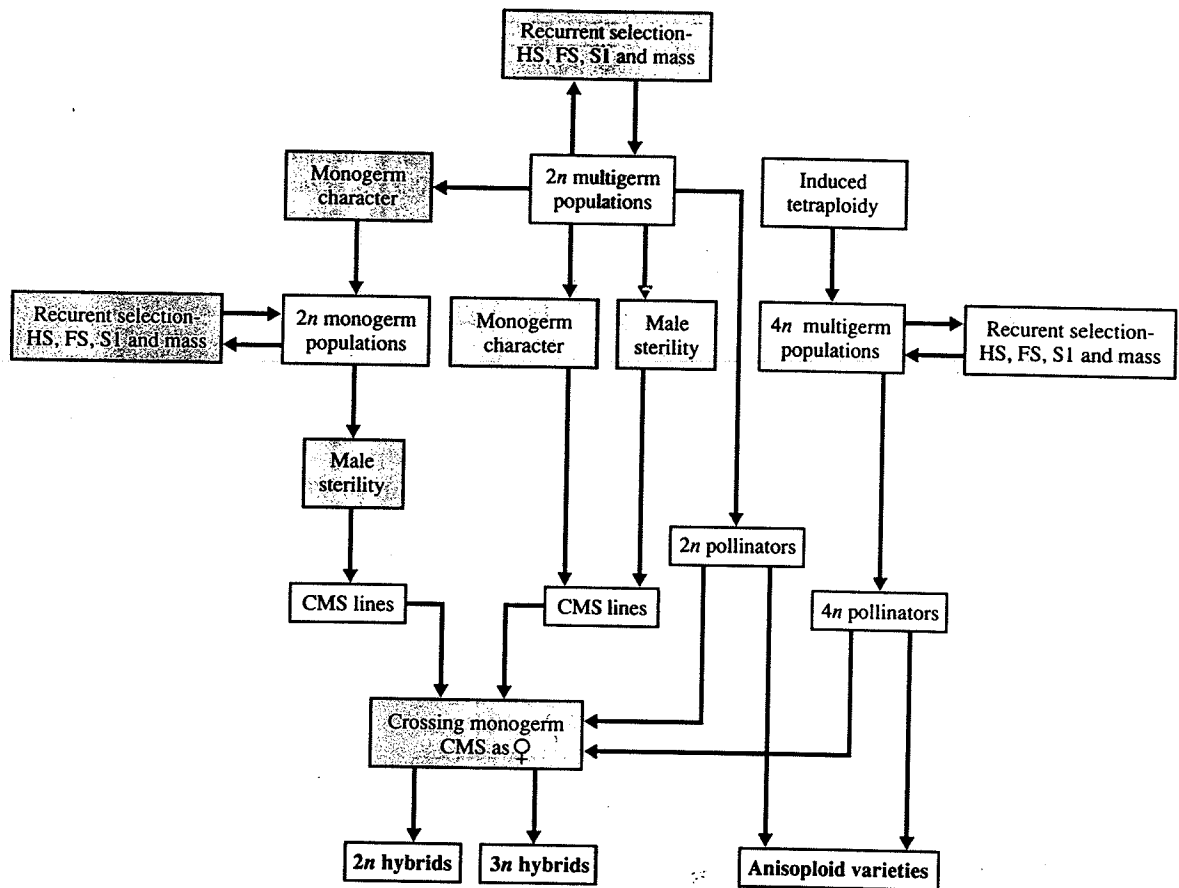


Fig. 11.2 Breeding systems in sugarbeet (HS = half sibs, FS = full sibs).

varieties are still used in some parts of the world, but are in decline, being replaced by true triploid varieties produced using cytoplasmic male sterility. This triploid production offers a means of improving yields of varieties carrying the monogerm character, a feature which was originally associated with poor root yield. With the superior genetic background of modern monogerm material, it is no longer clear that the advantages of triploid as opposed to diploid varieties are genuine. Breeding at the diploid level has always been pursued successfully in the USA, and is now making inroads into European varietal production. Breeding systems are illustrated in Fig. 11.2.

Monogermity is of great importance because it

allows for total mechanization of crop production. It was first exploited in the former Soviet Union and then the USA. A monogerm plant bears single flowers at each inflorescence node instead of a cluster of flowers which fuse during fruit and seed maturation to give rise to the more normal multigerm situation. Multigerm varieties must be singled by hand in the field after emergence, but this is avoided if monogerm 'seed' is precision-drilled. The monogerm character is an inflorescence character and is determined by the genotype of the seed parent. It is therefore possible to use a multigerm pollinator on a male-sterile monogerm parent in commercial hybrid seed production. Nearly all cultivars now being produced for cultivation in northern Europe and the USA are

monogerm, and their success has been dependent upon achieving very much improved field emergence even with earlier drilling.

As with some other crops, cytoplasmic male sterility (CMS) has facilitated the large-scale production of commercial hybrid seed. It was first discovered in sugarbeet by Owen in 1942, and lines derived from this material have been the sole source of CMS for all commercial hybrid varieties grown to this day. Concern over genetic vulnerability as has been illustrated in the maize crop, has led to searches for other sources of CMS which might be exploited (Bosemark, 1979). *Beta vulgaris* subsp. *maritima* has proved fruitful in this respect, although no varieties have yet been produced using such new CMS sources.

Diseases of sugarbeet were first tackled in the USA, when it was found that European cultivars such as the KW (Kleinwanzleben) varieties, favoured by the early US sugar industry possessed little disease resistance and were severely affected by curly top virus, cercospora leaf-spot (*Cercospora beticola*) or black root (*Aphanomyces cochlioides*). Breeding for resistance to such diseases has generally proved successful, in contrast to the situation with beet cyst nematode (*Heterodera schachtii*) which has caused serious losses in Europe and the USA since the middle of the nineteenth century. Progress has been difficult since no resistance has been detectable from within the crop itself. Several genes conferring strong resistance can be found in species of the *Patellares* section, and the portion of chromosome bearing the resistance has now been transferred to sugarbeet, even though no cultivars possessing this resistance are yet available. Rhizomania, a virus disease (beet necrotic yellow vein virus, or BNYVV) which is carried by the common soil fungus *Polymyxa betae* has received much attention in recent years. First recorded in Italy in 1955, the virus has spread through Europe and most recently into the UK, as well as to California and China and Japan, causing serious losses in yield. A number of cultivars possess degrees of tolerance to the virus, and several sources of resistance are being exploited to develop new varieties. Equally important are the virus yellows of sugarbeet (beet yellows virus and beet mild yellowing virus). Tolerant varieties have in the past been produced by mass selection. Subspecies *maritima* has shown useful resistance characteristics, and resistance to the aphid vector has also been identified.

Cultivars of sugarbeet are selected for being biennial, and those which exhibit the 'easy bolting' characteristic have smaller, more lignified roots resulting in a lower sugar yield and greater wear on machinery during processing. Bolting resistance is of considerable importance, therefore, in northern Europe and also in parts of the USA. Selection of favourable germplasm, using artificial vernalization treatments has given rise to commercially important breeding material for the development of cultivars which can now be grown further north in Europe, and which can be drilled earlier in the season, thus allowing for a longer growing season.

Processing quality, referring to the ability to extract sucrose from the root, is related to sugar content and juice purity, and both affect the value to the processing industry of any sugarbeet crop. Current breeding of sugarbeet, therefore, aims not only to maintain or improve the percentage of sucrose by fresh weight of root obtained under different growing conditions but also to reduce the levels of non-sucrose substances such as sodium, potassium and amino-nitrogen which interfere with sucrose extraction.

### Prospects

In relation to further manipulating the breeding system of beet to assist in varietal development, the characters of genetic male sterility and obligate self-fertility are now allowing for the use of  $S_1$  progeny testing for recurrent selection schemes. There has also been a move by some breeders towards utilizing tissue culture to propagate clonally material at one or more stages of the breeding cycle (Middleburg, 1990). There is clearly scope for increased use of such techniques.

Pest and disease resistance will inevitably represent a significant factor in any future breeding programme for beet, but the specifics will depend to some extent upon the country for which the cultivar is being developed. Examples of the use of genetic resources (IBPGR, 1989), in the form of wild species as sources of useful genes have already been mentioned. *Beta vulgaris* subsp. *maritima* needs to be highlighted because it has already yielded resistance to cercospora leaf spot, rhizomania (both the virus and fungal vector) and to virus yellows. Species of the section *Patellares* are the only known source of resistance

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to beet cyst nematode. It is reported that *Corollinae* section species possess resistance to all known beet viruses. Diverse genetic resources of beet will therefore become increasingly important for the future development of the crop.

Increases in the basic productivity of sugarbeet will come from improved methods of screening germplasm for desirable traits such as disease resistance, photosynthetic efficiency and drought tolerance. This in turn will be dependent upon better elucidation of the mechanisms which control for instance plant intermediary metabolism, or which determine yield, quality or phase-change. There are current research programmes which are aimed at increasing the protein levels of the sugarbeet root, so that the value of the pulp after sugar extraction which is used as cattle feed can be increased. A fundamental question to be addressed therefore will be whether higher protein will result in lower sugar levels. If a future aim of breeding is to further increase the juice purity of the sap, will this result in reduced stress tolerance?

Biotechnology and genetic manipulation will play significant roles in sugarbeet crop improvement (Newbury *et al.*, 1989). It is now possible to transform sugarbeet genetically in order to obtain full expression of a cloned gene. Breeding material is therefore now available expressing herbicide resistance, and within the near future, it is likely that sugarbeet will be available with genetically engineered resistance to BNYVV. Because the sugarbeet, in comparison to many other crops, produces a high yield of dry matter per hectare, and because of the knowledge base, existing technology and investment in processing the crop, it is possible to envisage that sugarbeet may be genetically engineered to produce novel high-value chemicals in addition to the sucrose which is currently extracted.

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