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Beetroot
Beta vulgaris subsp. *vulgaris*

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BEETROOT is a very popular vegetable in eastern and central Europe, but is much less important in western Europe and the USA, where it is known as garden beet. It is grown for its swollen root and is the horticultural form of *Beta vulgaris* subsp. *vulgaris* ($2n = 18$) which also includes the agricultural types sugar beet, mangold and fodder beet. The species also includes chard (subsp. *cicla*) and sea beet (subsp. *maritima*), which is thought to be the ancestor of most cultivars.[6]

The earliest form of domesticated beet was leaf beet. The leaves were eaten and the roots were used for medical purposes only.[7] DeBock[7] considered that the first reliable reports of beet plants with a swollen root occurred in twelfth-century Arabic texts.[22] However, Campbell[6] states that beetroot featured in Roman recipes of the second and third centuries. Fourteenth-century English recipes also reportedly described the use of beetroot,[6] and sixteenth-century European herbals divided the beet crop into leaf beet (which was the major crop) and the dark-red, juicy beetroot.[7] The latter was exclusively for human consumption and it was not until the beginning of the eighteenth century that beetroots were used as fodder.[22] By the beginning of the nineteenth century fodder beet had become an integral part of the European mixed farming system. Sugar-beet evolved from fodder beet. Sugar-beet is a major temperate agricultural crop and as such has received much attention from plant breeders, pathologists and agronomists.[23] Although much of this research is applicable to beetroot breeding, the minor status of the horticultural crop has resulted in much less effort being expended on breeding research. Consequently there is often an appreciable delay before new developments in sugar-beet breeding are applied to beetroot. This chapter concentrates upon research that has been carried out directly upon beetroot.

Genetics

Colour

Investigations into the genetics of pigmentation in beetroot have shown both quantitative[24] and qualitative[14, 16, 19] control. Qualitative colour differences are determined by two loci. Five alleles, R, R^l, r, R^p and R^h, have been identified at the R locus and three alleles, Y, Y^l and y at the Y locus. The $R-Y-$ genotype determines a phenotype with red roots, hypocotyls and petioles while in the

presence of the recessive *rr* genotype *Y*− gives yellow roots, hypocotyls and petioles. The *R*−*yy* genotype roots are white with red hypocotyls. The double homozygous recessive *rryy* produces a yellow hypocotyl and white root. The R^{tt} allele gives a red hypocotyl only in the presence of the *Y* allele, R^{t} conditions striped petioles independently of the genotype at the *Y* locus, and R^{p} produces pink roots, hypocotyls and petioles. The Y^{r} allele determines pigment production in the roots only: thus $R-Y^{r}-$ plants have red roots and $rrY^{r}-$ plants have yellow roots but both have green tops, while $R^{t}-Y^{r}-$ plants have red roots and striped petioles. Keller[16] found the dominance relationships $R^{t} > R > r$ and $Y > Y^{r} > Y$.

Quantitative differences in the colour of red beetroot are determined by the ratio of violet betacyanin to yellow betaxanthine pigments. Roots with high, medium and low betacyanin to betaxanthine ratios have violet, red and orange colours respectively. Highly significant general and specific combining ability was found for both pigment concentrations and pigment ratio.[24] The ratio of betacyanin to betaxanthine was found to be controlled by a triallelic system at the *R* locus with incomplete dominance.[26]

Male sterility

Bliss[1] studied the inheritance of male sterility in beetroot. Male sterility was governed by the segregation of a gene *X* in S cytoplasm, with fertility dominant to sterility. A second gene *Z* conditioning partial male fertility was found; this was also completely dominant to male sterility, but was independent of and hypostatic to *X*.

Breeding Objectives

Although a few yellow-rooted cultivars exist, the main breeding objectives for beetroot are high yields of dark-red, uniformly coloured roots with absence of any internal white rings, resistance to bolting, and uniform shape and size. Cultivars may have spherical, flattened spherical, cylindrical or conical root shapes.[24]

Germplasm Resources

Beetroot is cross-compatible with all of the other forms of *Beta vulgaris* including the non-cultivated weedy types. This provides a vast array of natural variation[28] for plant breeders which as yet has remained largely untapped. The monogerm character and cytoplasmic male sterility (CMS)[9, 10] have been transferred from sugar-beet, but there is little published work on utilization of genetic resources for the introduction of pest and disease resistance. Hammer *et al.*[12] considered the genetic base of modern cultivars was narrow. Previously, however, Holland[13] had found great variation among beetroot cultivars. He classified over 200 cultivars into 40 groups on the basis of their root and foliage characteristics.

Hybridization Techniques

Beetroot is wind pollinated and is a very prolific pollen producer. Breeding work with this species therefore requires some form of pollen-proof conditions for isolation of plants. The near-impossibility of emasculating the flowers meant that

until the introduction of CMS from sugar-beet, cultivars were produced by mass pollination of selected roots.[25] The introduction of CMS into beetroot has meant that F_1 hybrid cultivars can now be produced.

Strategies and Methods

Beetroot will set self-pollinated seed but shows inbreeding depression. Although the introduction of CMS has resulted in the production of some hybrids, most cultivars are at present still produced by mass-pollination. Watts[25] suggested that if a large number of roots have been selected they should be divided into groups of not more than ten. These should be seeded together but separated from other groups (e.g. by a fine muslin cage). The mass pollinated seed should be harvested either from the group as a whole or from the individual plants. Further selections can then be made from the best progeny.

Chemical mutagens (dimethyl sulfate, DMS; *N*-methyl-*N*-nitrosourea, MNU; and *N*-ethyl-*N*-nitrosourea, ENU) and physical mutagens (gamma-ray and ultraviolet irradiation) have been used to induce variation in beetroot breeding material.[17] Mutations were obtained in the M_2 generation affecting root shape (with ENU and MNU), flesh colour intensity (ENU) and rosette development (ENU and DMS). The highest percentage of monogerm forms was obtained with ENU and MNU.

Tetraploid beetroot plants have been reported among the triploid progeny of crosses between diploid beetroot and tetraploid sugar-beet. These were produced for cytological and biochemical studies,[1] and although backcrossing to the diploid beetroot parent produced tetraploids which more closely resembled beetroot,[2] it seems unlikely that tetraploid cultivars will be produced.

Breeding Achievements

Disease resistance

The cultivar 'Avonearly' reportedly has good resistance to downy mildew (*Peronospora farinosa* f. sp. *betae*). Sources of resistance to powdery mildew (*Erysiphe communis* f.sp. *betae*) have been identified.[21] *Beta maritima* was used as a donor of resistance to *Cercospora* leaf spot (*Cercospora beticola*) but was found to be very susceptible to black leg.[5] However, F_1 and F_2 hybrids were produced with resistance to leaf spot and reduced susceptibility to black leg.

Agronomic traits

The bolting-resistant cultivar 'Avonearly' was bred by selecting from among a population derived from a large number of cultivars of the 'Detroit' type. The plants were raised early in the year and subjected to continuous light followed by cold treatment to induce bolting.[14] The level of resistance had then to be maintained by selection during seed multiplication.[8] The cultivar 'Boltardy' was bred using a similar method.[25]

Wolyn and Gabelman[27] used simple selection indices together with half-sib family selection to select for increased betalain pigment concentration and total dissolved

solids in two beetroot populations. They increased the pigment levels to 1.5 times that found in the cultivars used to produce the original populations. This level was twice that in cultivars currently used for production of red food colouring.

The monogerm character has been transferred to beetroot from sugar-beet. Initial monogerm cultivars had poor quality characteristics,[25] but more recently monogerm cultivars have been included in lists of recommended cultivars.[18]

Biotechnology

Many tissue culture techniques developed for sugar-beet[3] are applicable to beetroot. However, there has been very little published work directly on beetroot itself. Sabir and Ford-Lloyd[20] included four beetroot cultivars in a study of mass production *in vitro* of beet regenerants. They found that shoot culture of beetroot was unsuccessful, but obtained more success with regenerants from adventitious buds. Callus cultures derived from cotyledon explants were used by Girod and Zryd[11] to investigate clonal variability and light induction of betalain synthesis.

Future Prospects

Beetroot breeding programmes will continue to make use of information and technology derived from sugar-beet research. Greater use will be made of the monogerm character, and F_1 hybrid cultivars will become more popular due to their uniformity. However, it is unlikely that this will happen very rapidly and for the foreseeable future open-pollinated multigerm cultivars will continue to be grown.

The increased use of hybrid cultivars may lead to pest and disease problems due to crop uniformity, necessitating an increased effort in resistance breeding, a path already taken by sugar-beet breeders.

The banning of some synthetic food colourings and the search for natural alternatives[26, 27] may result in programmes aimed at breeding beetroot cultivars with high betalain pigment concentrations for use as an industrial crop.

Beetroot is a major vegetable crop in central and eastern European countries such as Poland and Russia. Consequently there has been a much greater research effort on the crop there than in the West. Previously much of the information produced by this research was not readily available to breeders in the West. It is to be hoped that in future improved access will lead to greater collaboration between breeders of this crop.

References

1. Akhramenka, G. D., Cytological and biochemical characteristics of polyploid forms of beetroot. *Vestsi Akademii Navuk BSSR, Biyalagichnykh Navuk 1988, 5*, 33, 1988.
2. Akhramenka, G. D. and Kazyrevich, T. P., Effect of backcrosses on alteration of characters in recombinant forms of tetraploid beetroot. *Vestsi Akademii Navuk BSSR, Biyalagichnykh Navuk 1989, 1*, 20, 1989.
3. Atanassou, A. I., Sugar beet (*Beta vulgaris* L.), in: *Biotechnology in agriculture and forestry, 2. Crops I*. Bajaj Y.P.S. ed., Springer Verlag, Berlin, 485, 1986.
4. Bliss, F. A., Inheritance of male sterility in table beets (*Beta vulgaris* L.). *Diss. Abstr. 25*, 6901, 1965.

5. Burenin, V. I. and Timoshenko, Z. V., Multiple disease resistance in beet. *Byul. Vses. Ord. Len. Ord. Druzhby. Nar. Inst. Rast. Imeni N.I. Vavilova 194*, 36, 1989 (in Russian).
6. Campbell, G. K. G., Sugar beet, in: *Evolution of Crop Plants*, Simmonds, N.W, ed., Longman, London, 25, 1976.
7. DeBock, Th. S. M., The genus *Beta*: domestication, taxonomy, and interspecific hybridization for plant breeding. *Acta Hort. 182*, 335.
8. Dowker, B. D., Bowman, A. R. A. and Faulkner, G. J., The effect of selection during multiplication on the bolting resistance and internal quality of Avonearly red beet. *J. Hortic. Sci. 46*, 307, 1971.
9. Gabelman, W. H., F_1 hybrids in vegetable production, in: *Proc. XIX International Horticultural Congress, Warsaw, 11–18 Sept. 1974 Vol. III*, Antoszewski, R., Harrison, L. and Nowosielski, J., eds., 419, 1974.
10. Gabelman, W. H., Breeding F_1 hybrid table beets, in: *Proc. XIX International Horticultural Congress, Warsaw, 11—18 Sept. 1974*, Vol. IB Antoszewski, R., Harrison, L. and Nowosielski, J., eds., 669, 1974.
11. Girod, P. A. and Zryd, J. P., Clonal variability and light induction of betalain synthesis in red beet cell cultures. *Plant Cell Rep. 6*, 27, 1987.
12. Hammer, K., Stanarius, A. and Kühne, T., Differential occurrence of beet cryptic viruses — A new tool for germplasm characterization and evolutionary studies in beets? *Euphytica 45*, 23, 1990.
13. Holland, H., Classification and performance of varieties of red beet. *Rep. natl. Veg. Res. Stn. for 1956, 16*, 1957.
14. Holland, H. and Dowker, B. D., The breeding of Avonearly, a red beet variety resistant to bolting. *J. Hortic. Sci., 44*, 257.
15. Kajamus, B., Genetische studieri an *Beta*. *Z. induktive Abstam. Vererbungslehre 6*, 137, 1912.
16. Keller, W., Inheritance of some major colour types in beets. *J. Agric. Sci. (Camb.) 52*, 27, 1936.
17. Litvinova, M. K., Frolova, N. F. and Bityutskaya, V. V., Use of experimental mutagenesis in breeding beetroot. *Byul. Vses. Ord. Len. Ord. Druzhby. Nar. Inst. Rast. Imeni N.I. Vavilova, 161*, 23, 1986.
18. National Institute of Agricultural Botany. Descriptive list of varieties of beetroot, calabrese, courgettes, parsnips, salad onions, celery, sweet corn, leeks, Chinese cabbage grown in NIAB trials. *Vegetable Growers Leaflet No. 7*, 30, 1991.
19. Pederson, A., The colours of beets (*Beta vulgaris* L.). *K. Vet-og Landbokojsk Arsskr.*, 60, 1944.
20. Sabir, A. A. and Ford-Lloyd, B. V., Processing crop plant germplasm *in vitro* for mass production of regenerants: a case study with beet. *J. of Biotech. 17*, 257, 1991.
21. Timoshenko, Z. V. and Burenin, V.I., Source of material for breeding beetroot and fodder beet for resistance to powdery mildew (*Erysiphe communis* Grev. f.sp. *betae* Jacz.), *Sbornik Nauchnykh Trudov po Prikladnoi Botanike, Genetike i Selectsii, 110*, 95, 1987.
22. Toxopeus, H., De historie van de Europese Kruisbloemige en bietegewassen. *Bedrijfsont-wikkeling 15*, 537, 1984.
23. Van Geyt, J. P. C., Lange, W., Oleo, M. and DeBock, Th. S. M., Natural variation within the genus *Beta* and its possible use for breeding sugar beet: A review. *Euphytica 49*, 57, 1990.
24. Watson, J. F. and Gabelman, W. H., Genetic analysis of betacyanine, betaxanthine and sucrose concentrations in roots of table beet. *J. Am. Soc. Hort. Sci. 109*, 386, 1984.
25. Watts, L., *Flower and vegetable plant breeding*. Grower Books, London, 179, 1980.
26. Wolyn, D. J. and Gabelman, W. H., Inheritance of root and petiole pigmentation in red table beet. *J. Hered. 80*, 33, 1989.
27. Wolyn, D. J. and Gabelman, W. H., Selection for betalain pigment concentrations and total dissolved solids in red table beets. *J. Am. Soc. Hortic. Sci. 115*, 165, 1990.