

Preface

This volume in the *Handbook of Plant Breeding* covers ten root and tuber crops in eight chapters: potato (*Solanum tuberosum*), cassava (*Manihot esculenta*), sweet potato (*Ipomoea batatas*), yams (*Dioscorea* spp.), taro (*Colocasia esculenta*) and cocoyam (*Xanthosoma sagittifolium*), sugar beet (*Beta vulgaris*), fodder beet (*Beta vulgaris*), and swedes (*Brassica napus*) and turnip (*Brassica rapa*). Although many of these crops were first domesticated several thousand years ago, none became important on a global scale until after the end of the sixteenth century. This brief introduction is a broad overview and inevitably a simplification of the details which follow in the individual chapters where unresolved issues are discussed.

The potato was domesticated in South America, cassava probably in South America but possibly in Mexico, and sweet potato probably in Mexico but possibly in South America, some 8,000 years ago. All three crops have wild relatives in both Central and South America. Much later, after Columbus discovered the New World in 1492, European sailors introduced the potato to Europe and from there to many other parts of the world, and both cassava and sweet potato to Africa and then Asia. Interestingly, the sweet potato was being grown in Oceania before Columbus, but the routes of introduction are still debated. Today the potato is the third most important food crop in the world, after wheat and rice, and the four largest potato producing countries are China, the Russian Federation, India, and the USA. Cassava is the most important root and tuber crop in the tropics where it is a primary staple food in many of the poorest countries, with the largest production in Nigeria, Brazil, Thailand, and Indonesia. The sweet potato is also a food staple in Asia, Africa, and America, but with production dominated by China, where half of the crop goes for animal feed. Yams are also important staple food crops in tropical and subtropical regions. The four main cultivated yams were independently domesticated on three continents some 7,000 years ago: *Dioscorea rotundata* and *D. cayenensis* in West Africa, *D. alata* in Southeast Asia and the South Pacific, and *D. trifida* in South America. Today, however, the major producers are in West Africa: Nigeria, Ivory Coast, Ghana, and Benin. Although taro and cocoyam are minor crops, they do provide a staple food for poor people in Africa, Asia, and America. Taro was domesticated some 10,000 years ago in Asia, Southeast Asia, and Melanesia, whereas cocoyam was domesticated in South America and subsequently taken in the sixteenth century to Africa and then Asia. Today the main producers of these crops are

Nigeria, Ghana, and China. The relative importance of all these crops can be seen from the 2008 FAO production statistics (<http://faostat.fao.org>): potato (314 million tonnes), cassava (233), sweet potato (110), yams (52), and taro and cocoyam (12); with sugar beet at 228 million tonnes.

The edible storage organs are underground tubers for potatoes and yams, storage roots for cassava and sweet potato, and corms/cormels for taro and cocoyam. All of these organs store energy as starch and the crops are viewed primarily as sources of carbohydrate energy when used as a food staple. They are, however, also valuable sources of minerals, vitamins, and other antioxidants. In addition, there is a trend toward using them to produce processed products for both human consumption and industrial use. All of the crops are vegetatively propagated: potatoes and yams through their tubers, cassava as stem cuttings, sweet potato as vine cuttings, and taro and cocoyam through side shoots, stolons, or corm heads. These propagation methods are slow, so more rapid ones have been, and are being, developed for the breeding and multiplication of new cultivars.

In contrast, sugar beet, fodder beet, swedes, and turnips are grown from true botanic seed and their above-ground storage organs are swollen hypocotyls with varying amounts of stem above and root below, often simply referred to as 'roots.' Their carbohydrate is primarily in the form of simple sugars, sucrose in beets and glucose and fructose in swedes and turnips. Sugar beet and fodder beet were both derived from the leaf and table beets grown as vegetables by the Greeks and Romans. Fodder beets, with larger roots, were developed during the 'Middle Ages' in Northern Europe for livestock fodder and became an important winter feed for cattle from the 1800s. After the discovery that temperate fodder beets contained the same kind of sugar as tropical sugarcane, the first sugar factory opened in Silesia (Poland) in 1802, and sugar beets were selectively bred from the 1800s. Today sugar beet provides about one-quarter of the world's sugar production from crops grown in temperate climates such as found in Europe and the northern USA.

The turnip, like table beet, was also a vegetable grown by the Romans, and probably the Greeks before. The turnip came to prominence as an agricultural crop as part of the four-field rotation (wheat, turnips, barley, and clover) which originated in Flanders and was introduced into Britain by Lord 'Turnip' Townshend about 1730. This led to the British Agricultural Revolution of the eighteenth and nineteenth centuries, which enabled the population base for the Industrial Revolution to take place. The origin of *B. napus* (swedes, oilseed, and forage rape), the allotetraploid of *B. rapa* (turnips) and *B. oleracea* (kales and cabbages), is uncertain, but it appears to have arisen several times in recent history. Swedes were first recorded in Europe in 1620 and introduced to Britain around 1780, where they were favored over turnips as having better keeping and feeding quality. By around 1870 the area of swedes and turnips in Britain had peaked at almost 1 million hectares. Today fodder beet, swedes, and turnips are minor crops for feeding to livestock in temperate climates such as Northern Europe and New Zealand, with swedes and turnips also grown as vegetables for culinary use. They have been replaced as major crops for animal feed by cereals and silage.

Since domestication, all of the crops have been improved by both conscious and unconscious farmer selection. More modern hybridization and selection by farmers, hobby breeders, and seedsmen occurred for potato, sugar beet, fodder beet, swedes, and turnips during the nineteenth century. These crops were therefore well placed to benefit from the birth of modern genetics in 1900 and the subsequent development of scientific breeding methods. Thus, for example, methods of producing hybrid cultivars to exploit heterosis for yield are available in the four crops grown from true botanic seed. Modern breeding of cassava and sweet potato started in the 1920s, but intensified really only from the 1960s and 1970s when breeding work also started to get underway for yams, taro, and cocoyams. This modern breeding work has been helped by the establishment of International Research Centers aimed at providing food security and eradicating poverty in developing countries; and this will remain important during a period of human population growth and climate change.

The extent to which the crops are benefiting from new biotechnologies reflects both their own economic importance and that of their close relatives. Thus the potato and cassava genomes have already been sequenced and that of sugar beet is due in 2011. Fodder beet breeding will benefit from advances with sugar beet and swedes and turnips from advances in their oilseed relatives. Molecular markers are available in all of the crops and are being used to characterize germplasm as well as resolve issues over domestication. Molecular marker maps have been produced and there are varying degrees of progress in using them for marker-assisted selection. Likewise genetic transformation is either available or becoming available to complement conventional breeding. It should be of particular value in the vegetatively propagated polyploids with complex inheritance patterns such as potato and sweet potato.

The new biotechnologies need to build on and integrate with past progress in breeding. It is still important to appreciate the reproductive biology of the crop, its evolutionary history, and the germplasm available to breeders. All of this is covered in each chapter in this volume, together with breeding methods and objectives, which fall into the broad categories of higher yields, better quality, and improved disease and pest resistance. While all of the harvested products of the crops considered are vegetatively produced storage organs, their breeding involves sexual hybridization and hence a knowledge of flowering, pollination, and seed set. In this respect, sugar and fodder beet, and swedes and turnips, are biennial species with a vernalization requirement for flowering. Swedes, unlike the other crops, are self-fertile and tolerant of inbreeding, despite being insect pollinated and having progenitors with sporophytic self-incompatibility. As expected, natural self-pollination occurs in potatoes as gametophytic self-incompatibility breaks down in polyploids, but the crop is not tolerant of inbreeding. Natural pollination is normally by wind in sugar and fodder beet and by insects in the other crops. Out-crossing is encouraged in some species by separate male and female plants (yams) or flowers (cassava, taro, and cocoyam), as well as by protogyny. In other species self-pollination is prevented by self-incompatibility which is gametophytic in sugar and fodder beet and sporophytic in sweet potato and turnip. Some of the crop species are regarded as diploids (cassava, taro, cocoyam, sugar and fodder

beet, and turnip), although sugar and fodder beet cultivars can be triploid as well as diploid hybrids, whereas other species are clearly polyploids. Swedes are an allotetraploid and the principal cultivated potato is an autotetraploid. Sweet potatoes are hexaploid (probably an allo-autopolyploid as a result of being a hybrid between a diploid and tetraploid species), and yams form a polyploid series, and incidentally are monocotyledonous.

Finally, there are also nine lesser known root and tuber crops native to the Andes of South America and cultivated by indigenous farmers. They have edible underground organs and are used both as subsistence and cash crops. Not enough breeding work has been done on them to justify a chapter in this volume, but further information is available from the International Potato Center (CIP) in Lima, Peru (<http://www.cipotato.org>), where accessions have been 'Held in Trust' since 1990 in their genebank, and some research has been done. A few brief comments will indicate why they are of interest. Achira (*Canna indica*) has rhizomes which contain large starch granules and hence high-value starch. It is also grown in Vietnam for noodles. Ahipa (*Pachyrhizus ahipa*) is a legume crop which produces carbohydrate-rich (starch and sugars) tuberous roots. Arracacha (*Arracacia xanthorrhiza*) has tuberous storage roots which provide starchy food free from undesirable substances. It has been introduced to Brazil where some breeding work is being done. Maca (*Lepidium meyenii*) is a root crop that can be grown at the upper altitude limits for agriculture and is of interest for its medicinal properties. Mashua (*Tropaeolum tuberosum*) produces yellow-fleshed tubers with a high carbohydrate content, both starch and sugars. Mauka (*Mirabilis expansa*) has fleshy edible storage roots high in carbohydrate and protein. Oca (*Oxalis tuberosa*) is a tuber crop which has also been grown in New Zealand for over a century, and where recent breeding work has led to the release of a new cultivar. Ulluco (*Ullucus tuberosus*) produces starchy tubers and has also been introduced to New Zealand as a new food crop where some research has been done on its yellow and red betalain pigments. Yacon (*Smallanthus sonchifolius*) produces non-starchy roots which contain high levels of sugars and fructooligosaccharides which can be used as sweeteners for diabetics. It was introduced from New Zealand to Japan in 1985 where a new cultivar, Saradaotome, has been bred.

In order to provide uniformity with the other volumes in the *Handbook of Plant Breeding*, each chapter is divided into the following sections: Introduction, Origins and Domestication, Varietal Groups (where appropriate), Genetic Resources, Major Breeding Achievements, Current Goals of Breeding, Breeding Methods and Techniques, Integration of New Biotechnologies in Breeding Programs and Seed (Tuber/Commercial) Production. The length of each section varies with crop, as appropriate, and I tried to give the authors of chapters as much freedom as possible within this overall framework. We hope that the finished product will be of value both to students of plant breeding and professional plant breeders, as well as to anyone interested in this fascinating group of root and tuber crops.

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