

## Introduction

THE BIOLOGY, HISTORY and development of citrus fruits have aroused worldwide interest. This has been enhanced, to a large degree, by the uniquely attractive appearance of the fruit and by its medicinal properties.

Citrus fruits originated in South East Asia and spread during the Middle Ages, later to become established in all continents. Citrus is by far the most important evergreen fruit crop in world trade. The fruit's special structure and long shelf life have facilitated its large-scale export as fresh fruit. Processed juice products, on the other hand, have also become increasingly important worldwide.

The exact origin of *Citrus*, its ancestral types and systematics are still largely unknown. The great wealth of citrus types and cultivars of today reflects the vast natural breeding options within *Citrus*, as well as effective intentional human intervention. Molecular genetics, which has been a most helpful tool in unraveling the secrets of the past, also opens new vistas for breeding work in the future. Modern citriculture has adopted parthenocarpy and seedlessness for all major citrus types. Present-day cultivars represent largely subtle gene combinations conserved by vegetative propagation on seed-propagated, apomictic rootstocks.

Classical citriculture achieved the highest fruit quality in subtropical areas. Low temperatures and frost hazards limit the expansion of citriculture into cooler domains. Citrus has always been known to be highly dependent on irrigation in most environments. Water relations and mineral nutrition have been extensively investigated. The significance of viral diseases for the survival and propagation of citrus has become increasingly evident during the present century. The noticeable increase in marketing standards has dictated the adoption of strict disease- and pest-control strategies, involving extensive use of pesticides and fungicides. The development of biological pest-control measures is one of the most important achievements in this area.

The vegetative and reproductive physiology of citrus has been studied in great detail, with fruit growth and maturation receiving considerable attention. Prolonged storage and the overseas export trade have stimulated the study of postharvest physiology and pathology. The rise of the processing industry promoted detailed investigations into the chemical composition of the fruit.

### **Pressure for change**

Citrus, in common with many other fruits, has expanded worldwide and is subject to universal trade. Citrus production is concentrated in many subtropical climates with irrigation (Mediterranean, California, South America, S. Africa, Australia) and is found to an even larger extent in the humid subtropical climates of Brazil and Florida. Particular developments in the cooler climate of Japan and expansion in the ancient habitat of China have also taken place. Marked differences have been observed in tree and fruit response under varying climatic conditions in arid, subtropical, tropical and marginal environments.

The search and adoption of seedless cultivars can be considered a major innovation. The effects of rootstock and of juvenile characteristics seem to be pronounced to a much larger degree than in any other fruit tree.

Significant progress has been achieved in irrigation and fertilization practices, pests and disease control, fruit storage, shipment and processing and cold protection.

Noteworthy progress has occurred in the field of citrus protoplast culture and fusion, and, recently, also in transformation techniques and in the contribution of molecular biology to the study of viruses.

Citrus culture has evolved in many areas with outstanding success; however, costly failures and weighty problems also abound.

Citrus groves are almost universally threatened by climatic hazards, viruses and decline diseases. Pressures for changes in cultivars, rootstocks and cultural practices are large. The biological control of insects, which has had a success unparalleled in other crops, faces new tasks. Soil and irrigation water salinity abound in many otherwise suitable environments. Further demands for changes in methods of production will prevail through economic and social forces. Chemical crop protection is both expensive and disquieting to the public. New pests and diseases emerge and are being disseminated. Though noteworthy progress has been achieved in the control of many destructive viruses, problems caused by certain viruses still greatly influence rootstock and scion selection. The

replacement of chemical control by genetically engineered resistance emerges as a subject of high priority. Limitations on the manifold uses of growth substances in citriculture may well also be imposed in the future.

Social and economic pressures also call for the simplification of cultural methods, earlier fruit bearing and, possibly, new fruit types and products. While the selection and, recently, the breeding of seedless fruit has progressed measurably, aspects of self compatibility, pollination requirements and various aspects of seed formation still require further elucidation.

In contrast to the success achieved in affecting external fruit appearance and freedom from blemishes, successful influence on the internal quality and composition has been rather elusive.

The picking of citrus fruit involves substantial labor. Attempts to introduce large-scale mechanical picking or to facilitate fruit harvesting by chemical means (such as ethylene secreting substances) have not yet been successful enough. An increasing share of the world's citrus crop is consigned to industrial purposes, along with a steadily diminishing proportion for fresh fruit use, a trend having widespread implications as to choice of cultivars and management practices.

This book was written in a belief that a comprehensive compact, up-to-date exposé of citrus biology will contribute to the study, teaching and exploration of citrus.

# I

## History and growing of citrus

### History of citrus

THE TERM CITRUS originated from the Latin form of '*Kedros*', a Greek word denoting trees like cedar, pine and cypress. As the smell of citrus leaves and fruit was reminiscent of that of cedar, the name citrus has been applied to the citron. Linnaeus grouped all citrus species known to him in the genus *Citrus*. In Greek mythology citrus fruits are called hesperides.

The suggested origin of the true citrus fruits is South East Asia, including South China, north-eastern India and Burma. Evidence from wild citrus in the area is still unclear. In many cases, seed has been spread large distances from the sites of origin and culture by birds, water streams and human activity. Tolokowsky (1938) considers the centre of origin to be the mountainous parts of southern China and north-eastern India, where sheltered valleys and southern slopes are protected from cold and dry winds yet are exposed to the warm rains of the summer monsoon. The deciduous *Poncirus trifoliata* grows wild in central and northern China.

While according to certain authors (Tanaka, 1954; Jackson, 1991) citrus fruits may have originated in north-eastern India and Burma, the introduction of citrus into cultivation and the probable origin of several species started in China. Table 2.2 gives the principal species of *Citrus* and their probable native habitat, according to Cooper and Chapot (1977). Lemon and grapefruit are not considered true species.

Domestication could have started independently in several locations in the area mentioned above or even in a broader area. There are indications of early cultivation of citron in India, and of mandarins and possibly other citrus fruit in China. The wide diversity of citrus in Yunnan has recently been described (Gmitter and Hu, 1990). Rivers arising in or traversing Yunnan could have served as dispersal mechanisms to the south.

Ancient dynasties of China regarded citrus as highly valued tributes

(Tolkowsky, 1938; Webber, 1967; Needham, 1986). The earliest mention of citrus fruits in Chinese literature occurs in the list of tribute articles sent to the imperial court at An-Yang (near the big bend in the Yellow River) during the reign of Ta Yu (c. 2205–2197 BC), as given in the *Shu Ching* under the section entitled *Yu Kung* of the Chinese Imperial Encyclopedia (Cooper and Chapot, 1977). The text may be as old as the early eighth century BC or the late ninth century BC (Needham, 1986). Figure 1.1 shows wrapped tributes of *Chu* and *Yu*, sent from Yanchow. The term *Chu* included presumably both kumquat and small-fruited mandarins. The term *Yu* included probably both the pummelo (*Citrus maxima*) and the Yuzu (*C. junos* Sieb. ex. Tan.). *Chu* and *Yu* tributes were perishable and may therefore have been essentially mandarins and pummelos. One of the earliest traditions of the Chinese was the grafting of *Chu* onto *Chih* (the deciduous *Poncirus trifoliata*). Pummelo was probably multiplied by air layering (marcottage). There was no mention of *kan* in the list of tributes. *Kan* may have included large mandarin-type fruit and possibly also oranges. The first mention of *kan* was made in a prose poem by Ssu Hsiang-ju, who died in 188 BC. From the time of WuTi (140–87 BC) Canton had an official in charge of the imperial tribute of yellow- and red-skinned *kan* orange-type fruit. Mention of the sour orange (described as unfit to be eaten in the raw state) and kumquat (*Fortunella*) also appears in the above-mentioned period (118 BC). The first description of citron appears only later, by Chi Han (AD 290–307). Citron fruits shaped like melons are described. Citrons originated most probably in India. Recently, a report of citron trees claimed to be indigenous has come from China. Han Yen Chih, in a monograph on citriculture in 1178 AD, described 27 cultivars of citrus. The earliest reference to citrus fruits in India appears in a collection of devotional texts around 800 BC, named *Vajasaneyi samhita*. Lemon and citron are specifically mentioned under the name of *jambila* (Tolkowsky, 1938). Names for oranges appeared in India for the first time in the oldest Sanskrit medical work about 100 AD (Tolkowsky, 1938). The Sanskrit name *nagarunga* has become *aurantium* in Latin, and orange in English (Jackson, 1991).

The role of the Shan race, also known as Tai, who were once dominant in Southern China and then forced to move west and southward into Burma and Assam, in producing and propagating and distributing citrus is not fully known. *Kan* oranges are still propagated today by seed in the Khasi hills of Assam.

The denotation of *Yau* in ancient Cantonese means pummelo fruit of the Yau people (the Tau race). High-quality pummelo cultivars and culture have developed in Thailand, where Tai people settled between the eighth and thirteenth centuries AD, essentially following the mode of propagation



Figure 1.1 Tribute of citrus fruit described in the Yu Kung chapter of *Shu Ching*. A late Ching representation from the *Shu Ching Thu Shuo*. From Needham (1986), reproduced with permission

(air layering) and culture of pummelo adapted in the flooded delta regions of China.

The sweet orange probably originated as a natural hybrid between the two species, pummelo and mandarin, grown in China in mixed village gardens. Human activity and interference of habitats confounded evidence that sweet oranges originated in the tropical rain forests of Upper Burma and Assam (Hooker, 1897; Tanaka, 1954). Probably, orange culture migrated from Yunnan to Upper Burma and eventually to Assam (Cooper, 1989). Sweet orange seed, which is apomictic, may have become naturalized later in the tropical rainforest region. It is postulated that sweet orange migrated from south-west China to Upper Burma rather than by the reverse path (Cooper, 1989).

The citron (*C. medica*), which is probably native to India, was not mentioned in Chinese writings until the fourth century AD. The citron was the first citrus with which the Europeans got acquainted and was perhaps for many years the only one known. The establishment of the citron in Media (Persia) appears to have occurred not later than the first half of the first millennium BC. It is assumed that it was first introduced by Alexander the Great to the Near East and Greece and it has been described by Theophrastus and called Persian (Median) apple. Evidence that citron was established at an earlier period in Egypt and Mesopotamia is rather inconclusive (Tolkowsky, 1938). Citron was appreciated for its medicinal properties, as an ornamental, for its fragrance and as an antidote to poison. It played a prominent part in Jewish religious rituals, appeared on Jewish coins during 66–70 AD, and has been a favorite motif in Jewish art since then (Figure 1.2). Caesarea was one of the main centres of citron culture. It was widely grown in Italy during the Roman period, probably as early as the first century AD.

A sculpture dating from the classic Hellenistic period clearly depicts lemon fruit, as well as the citron (Figure 1.3). The lemon, in addition to the citron, was known to the Romans, as evidenced by several mosaics and frescoes from the Roman era, including a mosaic from Tusculum dated 100 AD (Calabrese, 1990).

The Arabs were also well acquainted with the sour orange, and they have been instrumental in expanding citriculture to many areas. Expansion of sour orange culture occurred not later than the tenth century AD. Albertus Magnus (1193–1280) described the sour orange, calling it Arangus. By about 1150 AD citron, sour orange, lemon and pummelo had been introduced by the Arabs into Spain and northern Africa.

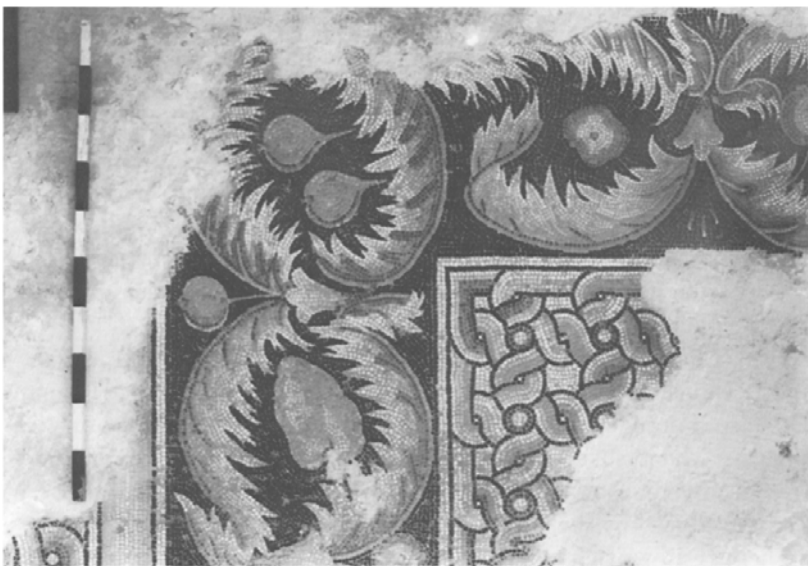
There is no written evidence of the actual culture of sweet orange in Europe before the fifteenth century AD. There are certain signs of earlier culture of the sweet orange (Tolkowsky, 1938). Citron, lemons and orange

fruit, attached to cut branches, are clearly depicted in a mausoleum built by Constantine the Great (274–337 AD). Evidence of lemon and orange cultivation in Italy during Roman times is, however, still contested (Tolkowsky, 1938; Webber, 1967). Sweet orange presumably reached Europe through the commercial route established by the Genoese. The fruit was of the low-acid, sweet type (orange douce). The Portuguese contributed further to the spread and cultivation of the orange by introducing a superior variety with a more balanced flavour (Figure 1.4). The name Portugal clung to the sweet orange and was so adapted in various languages (*portogalea* by the Greeks; *burtugan* or *bortugan* in Arab countries). This may have stemmed from the belief that the sweet orange tree from the original introduction was still growing in Lisbon, in the garden of the Count St Laurent (Gallesio, 1811). The Portuguese introduction certainly had a profound influence on citrus industry and trade.

The lime is probably native to the East Indian Archipelago. The first mention of it in Europe was in the thirteenth century (Webber, 1967).

The mandarin is a native of China and may have been grown there for thousands of years. It was introduced to Europe fairly recently – in 1805 from China to Great Britain and from there to Malta. It has assumed increasing importance in the European market only during the second half of the twentieth century.

The mandarin is the foremost citrus in Japan. The first reference of



**Figure 1.2** Citron fruit, mosaic floor of the Church of Nativity in Bethlehem (Fourth century AD). Israel Antiquity Authority



mandarin (Orange of Wenchou) in Japanese literature was made by Kokwan (1278–1346 AD). The famous Satsuma of Japan was named *Unshu-mikan* about 300 years ago. Tanaka (1932) suggested that it probably originated as a chance seedling in Japan during the Tang dynasty (618–907 AD). Mandarin seeds were brought to Japan from China, probably to Kagoshima on Kyushu island. A 300-year-old Satsuma tree



Figure 1.3 Cornucopia of the classical/Hellenistic period, in the National Archeological Museum of Athens, reproducing a citron (in the middle) and a lemon (on the right). After Calabrese (1990)

was found in Azuma-cho in Kagoshima, Kyushu. According to Chinese sources, a Buddhist priest brought back to Japan seeds from Unshu, China, giving rise to 'Satsuma' (*M. Iwamasa*, pers. commun.).

The kumquat (*Fortunella*) was introduced to the Royal Horticultural Society from China by Robert Fortune in 1846 AD.

In its journey to Europe the pummelo probably followed a similar path to that of the sweet orange and the sour orange. The Adam's apple, a form of shaddock, was mentioned as growing in the Holy Land around 1187 AD (Tolkowsky, 1938). It was brought to Spain by the Arabs at about the same period.

The pummelo is now widespread in Java, Malaysia, Thailand and Fiji. Some authors claim that it may have spread from the Malayan and Indian archipelagos to China and not vice versa. Calabrese (1994) states that the pummelo is of tropical origin (Malayan archipelago).

There are indications that seed of pummelo was brought to Barbados by Captain Shaddock, Commander of an East India ship. Pummelo tree and fruit is now often called 'Shaddock'.

Grapefruit (*C. paradisi*), now also classified as *C. maxima* var. *racemosa*, is almost certainly a hybrid pummelo. It originated in Barbados, and was first described under the name of 'forbidden fruit' by Griffith Hughes from Barbados in 1750 (see also Gmitter, 1995).

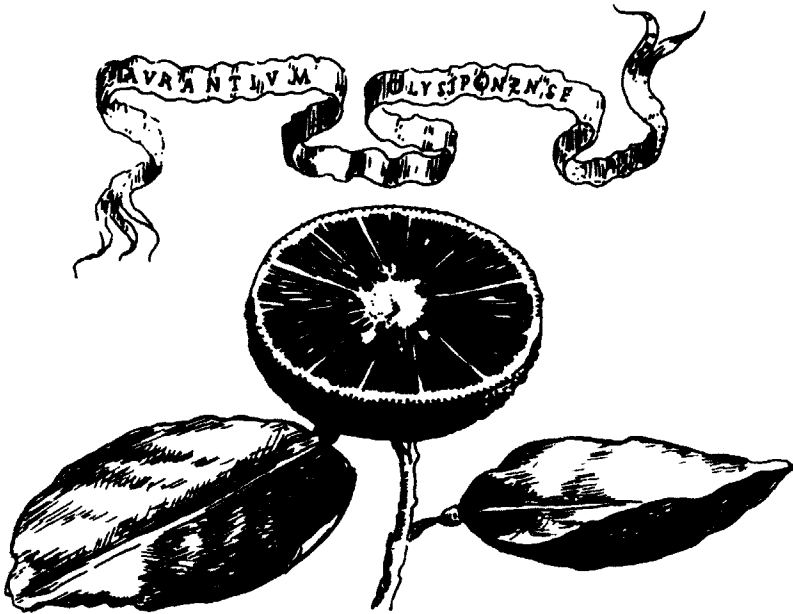


Figure 1.4 The Portugal orange as represented by Ferrarius in *Hesperides* (1646), named *Aurantium olysiponense*