POLISH SOCIETY FOR HORTICULTURAL SCIENCE

Folia Hort. 31(2) (2019): xxx-xxx

DOI: 2478/fhort-2019-0018

FOLIA HORTICULTURAE

Published by the Polish Society for Horticultural Science since 1989

REVIEW | Open access | http://www.foliahort.ogr.ur.krakow.pl

Ornacitrus: Citrus plants (*Citrus* spp.) as ornamentals

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ABSTRACT

The industrial production of citrus plants for ornamental use (ornacitrus) began in Italy at the end of the 1960s due to the need for many citrus nurseries to adapt their activities in a time of crisis for citriculture. Nowadays, the ornamental citrus nursery sector is a well-established industry in many European countries such as Portugal, Spain, Greece, and southern Italy. In Italy, nursery production of ornamental citrus plants has become prominent due to the gradual shutdown of many commercial citrus orchards. Currently, Italy maintains its leadership with more than 5.5 million ornacitrus plants produced annually. Ornamental citrus production regards mainly different cultivars of *Citrus* and *Fortunella* species, with lemon as the lead species. In this paper, the contribution of breeding and cultural techniques to the innovation of the sector is reported and discussed. This review aims to give an updated scientific and technical description of a sector with large competitive potential that remains still largely unexplored, pointing out its strengths and weaknesses.

Key words: *Citrus* spp., nursery management, potted ornamental plants, rootstocks, variety

INTRODUCTION

Citrus L. is by far the most economically significant genus in the family Rutaceae. It accounts for some 25 species, native to the southeastern foothills of the Himalayas (Wu et al., 2018), that have spread everywhere between the parallels of 40°N and 40°S, and are now grown in 146 countries, in tropical and subtropical areas. Citrus is the main fruit crop in the world, and Brazil is the first producer country. In 2017, global production of citrus fruits reached 135.9 million tonnes (FAO, 2019), both for fruit consumption and juice production. Total citrus fruit production in the EU was 10.7 million tonnes in 2017. Spain (32.9%) and Italy (22.7%) are the main EU producers of citrus fruit (Eurostat, 2018). The use of citrus plants for both agricultural and decorative-medicinal purposes has a long history (Tolkowsky, 1938). The beautiful appearance of both tree and fruit, and the fragrance due to the characteristic essential oils have contributed to their cultural success all over the world (Webber, 1967). The first citrus to reach Europe, probably via Persia (Andrews, 1967), was the citron (*Citrus medica* L.), one of the few so-called "true species" (i.e. not of hybrid origin) (Nicolosi et al., 2000). Through the Jewish communities, the citron was traded over the entire Mediterranean region (Scora, 1975). At the time of the ancient Greeks and Romans, citrons were not considered edible and the plant was then used for decorative, medicinal, odoriferous, or symbolic purposes. In Italy, the citron's presence is recorded as far back as the 3rd century BC. Citrons are represented in frescoes and in mosaics in Pompeii, in the vault of the Mausoleum of

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Santa Costanza in Rome, in the Villa del Casale (Sicily), Carthage and other Roman sites in Tunisia. Archaeobotanical records established the existence of two Citrus taxa in Italy at least by the end of the 1st century B.C. and support the hypothesis that Citrus was a precious fruit that was used in sacred ceremonies (Pagnoux et al., 2013).

The sour orange (*C. aurantium* L.) was introduced into Europe between the XI and XII century, perhaps by the Crusaders, while the sweet orange (*C. sinensis* Osbeck) was introduced on several occasions three to four centuries later by Genovese and Portuguese navigators. In Sicily, its presence, under the name of arangiis dulcibus, is documented since 1487 (Bresc, 1972).

The lemon (*C. limon* (L.) Burm. F.), already known by the Romans, would be spread around in the XII century by the crusaders and/or by the Arabs. The mandarins (*C. reticulata* Blanco) and grapefruits (*C. paradisi* Macf.) were the last to be introduced in Europe in the XIX and early XX centuries, respectively.

Historically, the Muslim expansion throughout the Mediterranean area from the VIII century onwards played a key role in the diffusion of Citrus use and fostered a culture of "landscape stewardship", largely based on revolutionary forms of irrigated agriculture, especially in Andalusia and in Sicily. This is evidenced by the fact that nearly all the names applied to cultivated Citrus in Western languages were taken from the Arabic (Ramon-Laca, 2003), as were many technical terms in use for the irrigation techniques (Bresc, 1972). The Arabs, and afterwards the Normans in southern Italy, modelled their pleasure gardens (loca solaciorum) on the Persian model of the Pairidaeza, an earthly emulation of the Heavenly Dwelling-place (Barbera, 2015).

Between the end of the Middle Ages and the beginning of the Renaissance era, citruses were prized aesthetic and botanical components of gardens and plant collections across Europe, even at high latitudes that are too cold for the survival of the plants. This was possible because Citrus plants were grown in pots outdoors in summer and brought inside for winter, in greenhouses ("orangeries") (Webber, 1967; Recupero, 2009). This type of container-growing, with a preference for the strangest and most "bizarre" citrus fruits, became a cult for many aristocrats (Crescimanno and Sottile, 2007), and the culture of citrus plants became a status symbol. In Italy, particularly during the Medicean period, this phase of "citrusmania" that gripped Europe (Wearn and Mabberley, 2016) is well documented by the huge variety of Citrus species depicted in numerous herbals, paintings and engravings (Baldini et al., 1982; Baldini, 1990). Whereas commercial plantings and, successively, significant trade of fresh fruit started in Europe after the second half of the XVIII century, the history of the specialized ornamental sector is decidedly recent. Starting from the end of the 1960s, when an initial significant production of potted lemons took place in Tuscany, we have to wait until the end of the XX century for the development of a massive, specialized production of ornamental *Citrus* specimens, when small plants could be grown in plastic pots, making them easily transportable (Continella et al., 1992).

Nowadays, the ornamental citrus nursery sector is a well-established industry in many countries such as Portugal, Spain, Greece, and Italy. In southern Italy, from where most of the ornacitrus imports to northern Europe come from, production of citrus plants for ornamental purposes has become more important than traditional citrus nurseries (Del Bosco, 2003) due to the gradual shutdown of commercial citrus orchards started in the early 1990s (Schimmenti et al., 2009). Currently, Italy maintains its leadership, with more than 5.5 million ornacitrus plants produced annually in Tuscany, Liguria, Apulia, Calabria and, for more than 90%, in Sicily. Additionally, the interest in citrus as ornamental plants has increased in recent years also in different non-EU countries such as Brazil, Turkey or Indonesia (Dos Santos et al., 2015; Uzun et al., 2015; Budiarto et al., 2017), motivating the emergence of the new word "ornacitrus" for the ornamental citriculture (Dutt et al., 2016) including four groups: potted plants, mini-fruit plants, hedges, and landscaping plants.

This review is a compendium of the technical innovations applied to ornamental citrus potted plant production, starting from plant material selection up to rootstocks, varieties, substrates, training systems and cultural techniques ordinarily applied in the modern citrus nursery industry in Sicily.

ORNACITRUS NURSERY INDUSTRY IN SICILY

An extremely rapid expansion of surface areas and production volumes has characterized the structure and the organization of the ornacitrus nursery sector in Sicily in the last three decades (Russo, 1990; Continella et al., 1992; Calabrese

and De Michele, 1995; Recupero et al., 2001, 2003a; Bucca and Zarbà, 2004; Crescimanno and Sottile, 2007; Schimmenti et al., 2009). From an initial, collateral activity carried out in Citrus nurseries mainly devoted to the production of plants for fruit crop orchards, a gradual but intense process of specialization has been experienced by the sector. This process has regarded mainly the species composition, varietal aspects, rootstocks and propagation techniques, and was driven by scientific and technical innovation gathered both at local and international levels (Recupero et al., 2003b; Torrisi et al., 2004; Reforgiato Recupero et al., 2005; Recupero et al., 2015; Dutt, 2016).

Currently, Sicily has about 400 citrus nurseries with a total surface area of more than 300 hectares, located mainly along the coastal line, in the districts of Messina and Catania (Schimmenti et al., 2009; Recupero et al., 2015). At least 60% of the nursery area is maintained under covered structures to obtain a more rapid growth and to improve plant characteristics. Only a few nurseries carry out a complete production cycle, i.e. from seed to market, while most of them, smaller in size, deal with different kinds of semi-finished products. Their production is primarily exported to northern Europe (Germany, England, France and Scandinavian countries). The most important species is lemon (*C. limon* (L.) Burm f.) – about 50% of production, followed by calamondin (*C. madurensis* Lour.) – 20%, 'Oval' kumquat (*Fortunella margarita* (Lour.) Swing.) – 15%, and chinotto small leaf (*C. myrtifolia* Raf.) – 7%. Other species are quantitatively less represented.

THE GENOTYPES: CULTIVARS AND ROOTSTOCKS

In theory, most of the species belonging to the Aurantioideae sub-family of the Rutaceae could be used as ornamentals due to their particular morphological characteristics: evergreen bright leaves, beautiful scented flowers, attractive and persistent fruit (Continella et al., 1992). Ornamental citrus production regards mainly different cultivars of *Citrus* and *Fortunella* species. Currently, a large part of the citrus used in the ornamental sector are the same commercial cultivars normally utilized for fruit production. Very often, the ornamental sector is interested in exploiting the existing cultivars in the citrus germplasm collections or botanical gardens, with special reference to minor or neglected varieties for fruit production, but with interesting aesthetic features (Del Bosco, 2003; Budiarto et al., 2017). Indeed, it should be borne in mind that the presence of fruit attached on the trees adds value to the attractiveness of the potted plants. More recently, deriving from specific projects, new accessions have been selected exclusively for their ornamental value (Mazzini and Pio, 2010; Dos Santos et al., 2015; Recupero et al., 2015; Bowman and Road, 2018).

A majority of the ornacitrus plant production in Italy belongs to the lemon (*Citrus limon* (L.) Burm.f.). This is still represented in Sicily by a rich germplasm consisting of at least 22 different varieties or landraces (Siragusa et al., 2008). The most represented lemon cultivar for ornacitrus is 'Lunario' (Recupero, 2009). This is an ancient, distinctive Italian variety of decreasing importance for fruit production in parts of Sicily. The National Museum at Naples has two frescoes from Pompeii in which ripe 'Lunario' lemons, among others, are depicted (Andrews, 1961). Its basic description (Hodgson, 1967) reports: "*Fruit medium-large, long elliptical to long-obovate; commonly with well-developed neck or furrowed collar; usually with narrow sharp-pointed nipple; seedy. Rind smooth and medium-thin. Flesh colour greenish-yellow; not very juicy; only moderately acid. Tree of medium vigour and size, strongly overbearing, thornless; foliage dark green; highly productive*". Above all, its specific flowering abundance and frequency, the elongated shape and persistence of the fruit, and the deep green coloration of the canopy are all positive traits contributing to increasing the attractiveness of this cultivar for ornamental use.

Other frequently used lemon cultivars belong to the Femminello Group of lemon, which is the most important lemon group in Italy. They grow vigorously and are of moderate size at maturity. The trees tend to have few thorns and flower and set fruit throughout the year. There are a number of named selections within the Femminello Group and fruit characteristics vary with the selection (Hodgson, 1967). From a genetic point of view, some of them are considered very close to each other (Gulsen and Roose, 2001). For ornacitrus, the most utilized selections are: 'Femminello Carrubbaro', 'Femminello Quattrocchi' and 'Femminello Zagara Bianca'. The first two selections are both with a dense canopy and a characteristic cluster fructification with a great aesthetic value, the last one is appreciated for the large flower size and the abundant and early fructification, as well as for a certain tolerance to the "Mal secco" disease

Figure 1. *Citrus mitis*: widespread because of its flexibility in terms of different plant shapes, ranging from small to large, and from potted to trellised trees

(*Phoma tracheiphila* (Petri) Kantsch. et Gick.) (Recupero, 2009).

The calamondin (*Citrus madurensis* Lour. or mitis Blanco) is also considered an interesting ornacitrus for its everblooming habit, early and abundant fructification, easy propagation and cold-resistance. The tree form is erect, slender, densely branched, and the leaves are small and dense, giving the tree a decorative appeal. The fruits are very small, round, and orange at full maturity. The calamondin is widely used as an ornamental also in Florida and California, where a variegated form 'Peters', with marbled leaves and faintly-striped fruit is cultivated (Morton, 1987). In Sicily, it is currently considered one of the most successful species in the sector (Fig. 1), even if it suffers from the lack of fruit in the peak demand periods (April-May). To overcome this problem, a partial solution is to apply forcing techniques based on the imposition of a strong summer stress followed by irrigation (Calabrese and De Michele, 1995). Furthermore, calamondin shoots tend to bend under the weight of the fruit, with the consequent loss of aesthetic value (Recupero et al., 2003a).

The genus *Fortunella*, i.e. kumquats, is particularly prized for the cold-hardiness, the abundant bloom and the well-balanced and persistent fructification. *F. hindsii* (Champ.) Swing., *F. obovata* hort. Ex Tan. and *F. margarita* (Lour.) Swing. are the most used species (Fig. 2). The *F. hindsii* species is valued for the early maturation of its very small fruits, brilliantly coloured, subglobose,

Figure 2. *Fortunella* spp. are strongly requested due to their ability to simultaneously bear fruits and flowers

virtually inedible fruits and the small size of the plant (Hodgson, 1967), while the most widespread *F. margarita* species (Nagami Kumquat), is prized for the abundant and characteristic summer flowering (July). The fruits mature in late winter, holding well on the tree.

The commercial interest of the ornacitrus nurseries is focused on the production of market-driven particular plant features such as the appearance of the fruit, its shape and colour, or morphological anomalies that usually create curiosity and interest. This last aspect is the case with the Buddha's Hand citron (*Citrus medica* L. var. *sarcodactylis* (Hoola van Nooten) Swingle), very popular in home gardens for the characteristic shape of the scented fruit, which is split into a number of finger-like sections. However, this tree is very sensitive to frost, defects in the quality of the crown, and is easily affected by specific pest diseases (Sottile and De Pasquale, 2012).

A multitude of forms, colours, and leaf morphologies can also be found within the large family of the sour orange (*C. aurantium* L.), bergamot (*C. bergamia* Risso e Poit.), chinotto orange (*C. myrtifolia* Raf.), lime (*C. aurantifolia* Christm. Swingle), sweet orange (*C. sinensis* (L.) Osbeck), clementine (*C. clementina* Hort. Ex Tan.), citron (*C. medica* L.), etc. As a whole, this diversity has contributed to enlarging the market supply by the industrially managed nurseries (Fig. 3A-E). A survey carried out on the web-sites of some of the major Italian ornacitrus nurseries allowed to ascertain a minimum of 12 and a maximum of 20 different species listed in the catalogues. Among the lemons, the variation observed is of a minimum of 7 genotypes and a maximum of 64, including a lot of cultivars usually adopted for commercial fruit orchards. After the lemons, the highest diversity is registered for bitter and sweet oranges, accounting for 15 and 20 different varieties or selections in the average, respectively. Calamondin and *Fortunella* spp. are widely diffused as very small trees adopting the smallest pots, whereas grapefruits and citrons,

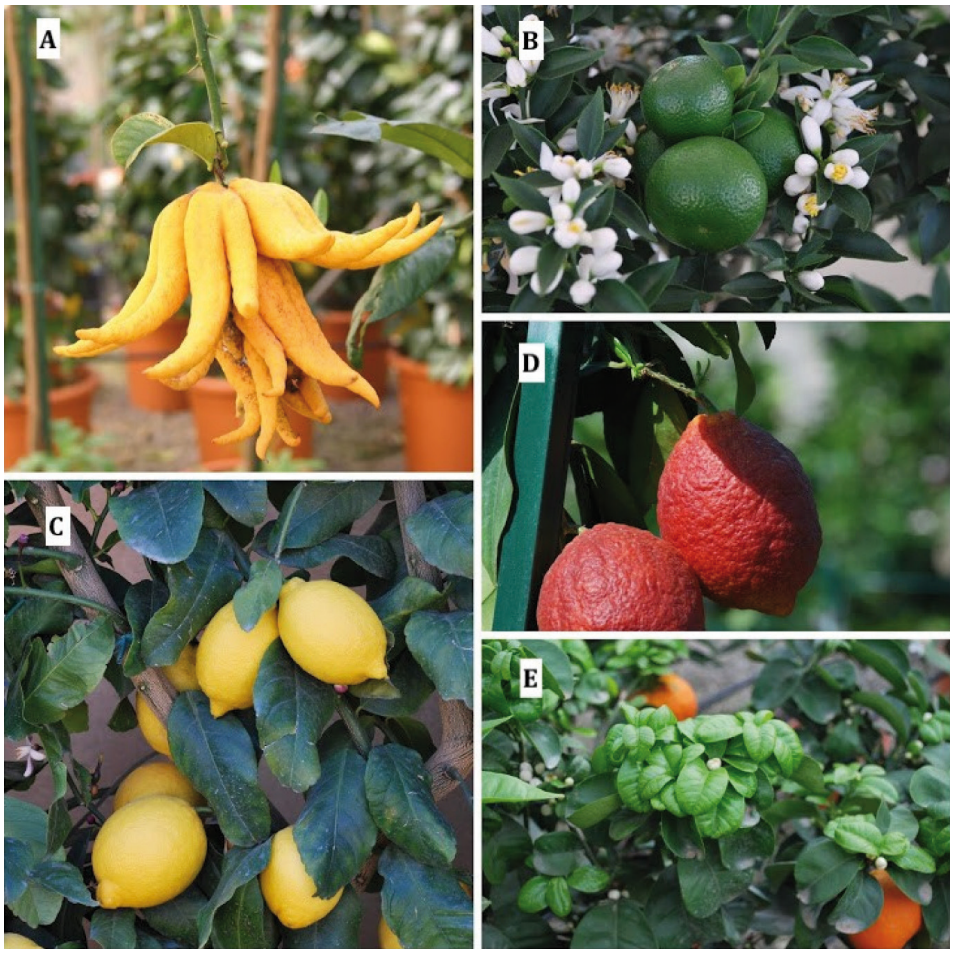

Figure 3. A representation of the genotypes most commonly used as ornamentals in the citrus nurseries: *Citrus medica* var. *sarcodactylis* (A), the Chinotto orange *Citrus myrtifolia* (B), the 'Lunario' lemon (C), the red lemon 'Limone Rosso ISA' (D), the 'Basil Leaf' *Citrus aurantium* (E)

being the tallest trees up to 3 meters high, require large pots.

Many recent breeding programmes have promoted the development of new citrus accessions for ornamental use with different fruit forms, plant morphology, fragrance and colours. Most of them are of hybrid origin [e.g. 'Red Lemon ('Limone Rosso') ISA'] or are derived from interspecific crossbreeding (e.g. 'Reale'), and sometimes with different ploidies (Recupero et al., 2001; Recupero et al. 2003a; Recupero et al., 2003b; Reforgiato Recupero et al., 2005; Recupero et al., 2015; Dos Santos et al., 2015; Dutt et al., 2016). 'Reale' is a triploid hybrid derived from 'Monreal' clementine × *Fortunella hindsii* 4x, and is considered of ornamental value as potted tree for its continuous blooming and early fructification. The canopy is compact and its thorns are short and thin. The foliage is more like that of kumquat than clementine. The fruit is small (≤ 15 g), yellowish and obovoid, and persistent on the tree. 'Red Lemon ISA' is a lemon hybrid of unknown origin. The tree is of medium vigour, with a globose canopy and not very spiny branches, of medium re-flowering. The flowers are white, medium perfumed, single or in small groups. Fructification is early and medium abundant. The fruit is large, very persistent, ellipsoidal, with a large apical nipple and an intense, attractive anthocyanic red colour on 70-80% of its surface when ripe.

'Amoa 8' is a hybrid between 'Moro' orange and 'Avana', mandarin, created at the CREA-OFA research station in Acireale (Sicily), as were the afore-mentioned 'Limone Rosso' and 'Reale'. The tree, early bearing, has moderate vigour and is prized as ornacitrus for the brightly coloured fruit contrasting with the bright green leaves (Recupero et al., 2015).

Great interest has been recently shown in a group of similar citrus relatives, i.e. *Microcitrus* spp., and specially in *Microcitrus australasica* (F. Muell.) Swingle (Australian finger limes). The finger lime tree is characteristically very thorny. It has shorter internodes than conventional citrus cultivars, with thorns as long as the leaves at every node. Apart from their aesthetic value as ornamentals, finger limes have become popular and command high prices as a specialty crop, and have been marketed as "citrus caviar" (Dutt et al., 2017).

The most utilized rootstocks for ornacitrus are currently the Volkamer lemon (*C. volkameriana* Ten. e Pasq.) or Alemow (*C. macrophylla* Wester), since they are both able to improve vegetative development and the number of fruit per tree (Recupero et al., 2001; Recupero et al., 2003a; Recupero et al., 2003b), whereas the sour orange, whose use was prominent in the past, has been discontinued due to its susceptibility to CTV (Citrus Tristeza Virus) and MSD. Trifoliate orange (*Poncirus trifoliata* (L.) Raf. is commonly used as a stock for ornamental citrus and in home orchards for dwarfed trees (Kester, 2002). In Sicily, it has been used mainly for kumquat and calamondin (Recupero et al., 2000) and so has, to a minor extent, its mutant Flying Dragon, which is considered decidedly dwarfing (Mademba et al., 2012). Other rootstocks such as Citrumelo Swingle, Citranges (Troyer and Carrizo), Rough Lemon and Cleopatra Mandarin are of minor importance.

Over the last few years, a number of citrus rootstocks, mainly of hybrid origin, have been created in breeding programmes and, as "recently released rootstocks", they must still be considered under evaluation (Castle et al., 2016). *In vitro* propagation has been reported as a viable alternative (Carimi and De Pasquale, 2003) to the traditional use of rootstock for the obtainment of own-rooted plants. This technique could also be useful in case of low rooting efficiency, such as in *F. margarita* and *F. obovata*, or *C. madurensis* (Recupero et al., 2003a; 2011). On the other hand, a rapid and efficient citrus rootstock propagation system by single node cuttings has been recently proposed and successfully applied either for research materials or for commercial nurseries (Bowman and Albrecht, 2017), with potential also for ornacitrus potted plants.

PRODUCTION TECHNIQUES

The ornamental potted citrus plant is produced in authorized nurseries structured in compliance with the current regulations of the European Union in order to prevent the introduction and the diffusion of alien plant pests (Eschen et al., 2015). The propagation material (seeds, scions, cuttings, etc.) must be from certified facilities. The mother plants are often grown in pots within screenhouses and are generally renewed every 5 years in order to avoid virus or phytoplasma transmission. This material must comply with the general rules currently applicable to the production of plants for plantings. This includes the availability of an adequate number of mother plants routinely controlled by the regional plant protection services by means of diagnostic molecular testing (i.e. PCR, RT-PCR, qPCR) for viruses and viroids (Rizzo et

Figure 4. Germinators are used to produce rootstocks in case the self-rooting procedure is not effective due to a natural low rooting efficiency

al., 2017). On the basis of the current legislation, any finding of quarantine pathogens in a nursery would involve the mandatory destruction of all the plants. Currently, the Tristeza virus (CTV – Citrus Tristeza Virus) represents a major concern since its diffusion in commercial fruit production orchards in Sicily (Davino et al., 2003), whereas the most widespread viroid identified in Tuscan ornamental citrus tree nurseries was CEVd (*Citrus exocortis viroid*), frequently observed in *C.* × *limonia* and *C. limon* together with a high frequency of mixed viroid infections (Rizzo et al., 2017).

Germinators, rooting trays with a heated bed for mist propagation, acclimatization greenhouses, shade-houses, potting machines, as well as structures and equipment for packaging and shipping, all represent the common equipment of a nursery working in the industrial production of ornamental trees in containers (Allegra and Zarbà, 2015) (Fig. 4).

Starting at the end of December, the seeds for rootstock production obtained from the mother plants are germinated on benches under protective structures. The plantlets (10-15 cm in height) are then transplanted into flexible nursery pots and maintained until they reach the minimum size (0.8-1.0 cm in diameter) for grafting, at about 15-18 months from germination. These seedlings are then bark-grafted with the selected scions in the late spring after the bark begins to slip and the buds are opening, ensuring a tight contact between the cambium zones. Volkameriana lemon (*Citrus volkameriana* Ten. & Pasq.) and *Citrus macrophylla* West. nucellar rootstocks are generally preferred, when available, for their uniformity due to their apomictic origin.

The grafted plant must be appropriately cared for in a nursery for at least 24 months from grafting before commercialization. Currently, the search for advancing commercialization has given rise to increased interest in the use of cuttings for the production of *C. limon*, *C. madurensis*, *C. medica* own-rooted plants. For this purpose, the technique of intermittent mist-propagation can be conveniently implemented with bottom heat supplied by hot water tubing (Kester, 2002). For best results in Sicily, leafy cuttings are obtained from mother plants in July.

Another rapid technique, which today is increasingly widespread in well-equipped nursery structures, is represented by cutting-grafts performed in April-May. It consists in the application of the mist-propagation method simultaneously to cuttings (Volkamer) and scions (selected cultivar), in which the scion and the rootstock are grafted together, and placed in a mist bed so that the rootstock produces roots and the graft heals at the same time (Fig. 5). This process is completed in a period of 60-70 days and, therefore,

Figure 5. Recently, new procedures for rooting already grafted vegetative portions have been established for many species

is notably less time-consuming than the traditional "seed – seedling – grafting" technique (Kester, 2002).

For both own-rooted and cutting-graft plant production, a dipping with a root-promoting compound (mostly IAA and NAA-based products) is profitably adopted.

The successful application of these procedures has conveniently shortened the production cycle of fruit-bearing ornamental citrus plants to only 18-24 months. Nevertheless, it depends on multiple factors:

- control of the relative humidity (RH) not below 80-90% inside the frame;
- the choice of an optimal rooting substrate (peat and perlite 1:1 v/v);
- a basal temperature of the bench not below 20°C;
- the proper application of root-promoting compounds at the base of the cutting (Blythe et al., 2007).

Other advantages obtained by excluding the sexual propagation of the rootstock include greater uniformity of plants. Furthermore, since the production cycle is shorter, a more flexible adaptation to changing market demand is achievable.

The ideal model plant is grown in a round pot of suitable volume (4 to 20 litres) and with a spherical canopy ("globe") inserted on a short (15 to 30 cm) main trunk with three to six (typically four) major branches. Nevertheless, small quantities of ornacitrus with other shapes are also produced: pyramid-shaped canopies at various heights, trellises of various sizes with one or more plants and bushes (Fig. 6). Generally, for shipping reasons, the height is limited to 2 metres or less.

Additionally, a small ornamental citrus tree must be generally trained in such a way as to have the following characteristics (Crescimanno and Sottile, 2007):

- rapid growth during the first year in order to reach soon the size for grafting
- rapid creation of a dense canopy, early bearing and with persistent fructification
- overlap between blooming and fruiting period
- regular architectural characteristic of the scaffold
- adequate root size in a shapely light pot, easily transportable (Fig. 7).

These objectives are generally achieved through appropriate training of the young trees. Pruning during the growth flush is aimed at obtaining the selected tree shape without interfering with early fructification. The first severe pruning is carried out when the root structure is sufficiently developed and well balanced with the canopy. Once the desired tree scaffold has been obtained, a series of light prunings, together with adequate mineral nutrition and the use during the cold season of gibberellin-biosynthesis inhibitors, are applied in order to promote blooming. From the onset of the blooming period until the end of the physiological fruit-drop, any additional pruning is avoided. In order to improve first flower bud formation, the application of plant growth regulators (PGRs) such as paclobutrazol has often been suggested for adult bearing trees (Martìnez-Fuentes et al., 2013; Tadeo et al., 2008) or for nursery trees (Le Roux and Barry, 2010). These PGRs, however, aside

Figure 6. Differently shaped ornacitrus for high value productions

Figure 7. The most common pots used for producing an ornamental citrus plant at the end of their production process, ready to be sold in the market

from not always being effective and not always having the same effect, have a particularly slow effect in citruses, which lasts over time and often negatively influences the vegetative growth while simultaneously also compromising the enlargement of the fruit (Horvath, 2009). In Italy, the use of paclobutrazol or prohexadione-calcium (ProCa) is allowed in the ornamental sector but not in the citrus production for direct consumption. However, nurserymen are using this kind of PGRs to reduce vegetative growth and promote abundant flowering in spring, and to advance early bearing (Recupero et al., 2003a). In any case, this application requires special attention when considering that ornacitrus could bear edible fruits.

The quality of the pot contributes to improving the appeal of the plant. The choice of the pot should be made considering the market demand, the ease of transportation, and also the desired marketable size of the potted tree, trying to reduce re-potting operations to a minimum. Currently, the most common container is a round pot, 20, 18 or 15 cm in diameter, of rigid polypropylene or polyethylene, of a 'terracotta' colour. Nevertheless, some advantages for the in-nursery management and the packaging/transport phase could be offered by smaller-sized containers (NeSmith and Duval, 1998).

The substrate composition is critical for the quality of potted plants. The most utilized components for growing medium are peat moss, perlite, coir, vermiculite and limestone. Some nurserymen have used in recent years mixed substrates inoculated with mycorrhizae (Glomus intraradices) (Ortas and Ustuner, 2014). A general mixture composed of peat moss, coir and compost (2:1:1 v/v/v) is largely adopted. Some recent studies have reported many other components positively affecting the growth and weight of citrus potted trees (Torrisi et al., 2004). The best substrates provide a balanced relationship between C and N, and a sufficient water retention capacity. It should be considered that any substrate offers its best performance during the first 10-12 months of cultivation in a container. For this reason, it has become a common practice to renew part of the substrate by partial periodic reintegration in the container. The factors that influence root growth in containers to achieve optimal benefits from container production together with selection criteria for an appropriate nursery substrate have been comprehensively reviewed by Mathers et al. (2007).

The water-mineral needs of the potted trees vary according to the phenological phase. Deficiencies or excesses of mineral nutrients can irremediably damage the plant mostly in terms of foliage colour and brightness (Srivastava, 2012).

The amount of water per application will depend on pot size, plant size, substrate humidity and, overall, plant physiological phase. In Sicily, ornacitrus nurseries apply irrigation daily from the end of March to mid-November and every other day in the other part of the year. Bearing potted trees are watered by using a drip irrigation system equipped with 20 l h^{-1} drippers applying on average 10 l d^{-1} of

Table 1. Amount of minerals (g dm^{-3}) used in fertigation during two different phases of the annual production cycle in Sicilian nurseries

	N	P	K	Ca	Mg	Zn	Mn	Fe
Vegetative phase	4.91	1.00	3.75	2.70	1.00	0.11	0.16	0.16
Reproductive phase	3.94	1.00	4.14	1.63	1.21	0.11	0.16	0.16

water solution (including minerals) (Sottile and De Pasquale, 2012).

The mineral nutrient management has to be related to the substrate and to the irrigation water used. According to Zekri and Koo (1992), Mathers et al. (2007) and Recupero et al. (2001) fertigation is the best fertilization system also for ornamental citruses and slow-release fertilizers (SRFs) and, in the case of top-dressing, controlled-release fertilizers (CRFs) are the predominant types of fertilizer used in container production. The quality and the chemical composition of the water used for irrigation must be carefully monitored before adding minerals for fertigation in order to regulate electrical conductivity (EC). Citrus plants are very susceptible to the salinity of the nutrient solution (Levy et al., 1980). Leaf injury, growth suppression and yield decline are the most common symptoms of an osmotic stress able to determine a negative effect on the metabolic process in the cell (Al-Yassin, 2004). Mumtaz Khan et al. (2006) reviewed the best EC values in growing substrate for potted citrus trees ranging from 0.63 to 1.56 dS m^{-2}, also evidencing that values above 3.5 dS m^{-2} could negatively affect seedling growth. Thus, when the water's EC exceeds 0.5 dS m^{-2}, an inverse osmosis treatment is conveniently applied in order to eliminate excess elements before watering (Argo and Biernbaum, 1996). To this end, usually the water EC is continuously monitored in real time.

The applied nutritional protocols are fundamental for determining the correct balance between vegetative growth activity – indispensable for obtaining a dense, consistent and luxurious crown – and the consequent reproductive phase that must provide an abundant bloom, persistent fruit and contemporary blooming and fruiting (Saleem et al., 1995). The most widespread protocol currently adopted in the Sicilian nurseries is shown in Table 1. The number and the duration of the interventions varies according to the plant container size, the environmental conditions, the substrate and the phenological state of the plant.

As far as pest management is concerned, Sicilian citrus nursery growers consider the citrus leafminer *Phyllocnistis citrella* Stainton (Lepidoptera: Gracillariidae) and the citrus mealybug *Planococcus citri* (Risso) the most important pests in citrus nurseries (Conti et al., 2006).

THE GROWING ENVIRONMENTS

In Sicily, on the northern coastal lines, where the ornacitrus nurseries are mostly located , plant production can be easily managed outdoors, without any particular crop protection, but a great part of the major nurseries usually prefer to manage the entire growth cycle in a protected environment. This will avoid aesthetic defects that could negatively affect the final quality and the economic value of the product. Furthermore, by adopting specific covering techniques, it is possible to better manage the cold season, even without artificial heating.

The most widely used protective structures can be grouped into two different kinds: permanent anti-hail nets and plastic film for the coldest seasons, which are partially removable, mechanically or manually. These production environments are quite different, depending on the growth phase. Firstly, it is preferred to use a covering with a 50% shading net, which, in combination with adequate fertigation, improves tree growth and protects the plants from any risk of hail. In the final phase of the growth-cycle, the plants are transferred to greenhouses mainly covered with glass and with automatic opening systems for the ridge and the side walls in order to control humidity and regulate the temperature. The ideal growth temperature fluctuates between 24 and 28°C on average during the growth and flowering phase. It falls to an average of 10-15°C during the winter, which is usually quite mild in the production areas. In the summer, the temperature can reach high values (30-35°C). The relative humidity must be maintained between 50 and 70% to avoid fungal diseases. In some high-tech greenhouses, a fog system is automatically activated when the humidity falls below threshold values (Sottile and De Pasquale, 2012).

In order to avoid the transmission of diseases, especially those affecting the roots (Poole et al., 1981; Aryantha et al., 2000) and in accordance with the current legislation, a complete non-

woven fabric mulch covered with a 5-8 cm layer of medium-grade gravel to isolate the tree pot from the soil is generally adopted. It should also be said that in some cases the adoption of smooth concrete platforms represents the simplest alternative (Nambuthiri et al., 2015).

CONCLUSIONS

The world of the ornacitrus production is now entering a new era characterized by an increasing industrial high-tech system. This industry is now addressed towards new interesting markets which may be quite far from the production areas. Transport logistics continues to be in a developmental phase.

The production of ornacitrus in Sicily still presents strengths and weaknesses. Thus, the ongoing research and the improvement of shipping methods may help to increase the economic results. As a whole, an effective contribution may still be offered by the refinement of modern techniques of propagation (cuttings or cutting-grafts) that, aside from contributing to a greater uniformity of the product, sensibly reduce the production time and consequently increase the production efficiency. Further improvement is expected through the refinement of the aspects related to breeding, irrigation, mineral fertilization, substrate and container material (e.g. compostable compounds).

Special attention must be paid to the theme of sustainability due to high environmental costs deriving from the massive use of PGRs, pesticides and minerals. This aspect cannot be underestimated, especially in consideration of the possible fruit consumption at purchaser level. To this end, the use of specially developed certificates that have been recently introduced by some nurseries with regard to safe, clean and sustainably cultivated products must be further encouraged.

It should, however, be again emphasized that the production and management techniques described in this review regard the Mediterranean coastal areas with a tropical or subtropical climate.

ACKNOWLEDGEMENTS

The authors are grateful to Cassandra Funsten (B.A. at UC Berkley) for her kind assistance in editing the English language in the final version of the paper.

AUTHOR CONTRIBUTIONS

All the authors contributed equally to all aspects of this manuscript.

CONFLICT OF INTEREST

Authors declare no conflict of interest.

REFERENCES

Allegra V., Zarbà A.S., 2015. Performance di costi nell'azienda florornamentale: il caso del limone ornamentale in vaso. Riv. Econ. Agr. 271-309.

Al-Yassin A., 2004. Influence of salinity on citrus: A review paper. J. Cent. Europ. Agric. 5, 263-272.

Andrews A.C., 1961. Acclimatization of citrus fruits in the Mediterranean region. Agric. Hist. 35(1), 35-46.

Argo W.R., Biernbaum J.A., 1996. The effect of lime, irrigation-water source, and water-soluble fertilizer on root-zone pH, electrical conductivity, and macronutrient management of container root media with impatiens. J. Amer. Soc. Hort. Sci. 121(3), 442-452.

Aryantha I.P., Cross R., Guest D.J., 2000. Suppression of Phytophthora cinnamomi in potting mixes amended with uncomposted and composted animal manures. Phytopathology 90(7), 775-782.

Baldini E., Rossi F., Bassi V., Giannini E., 1982. Agrumi. In: Agrumi, Frutta e Uve Nella Firenze Di Bartolomeo Bimbi Pittore Mediceo. CNR, Parretti, Firenze, Italy.

Baldini E., 1990. Fruits and fruit trees in Aldrovandi's "Iconographia Plantarum". Adv. Hortic. Sci. 4, 61-73.

Barbera G., 2015. Maredolce-La Favara: the place, the Arab and Norman heritage, the changing landscape of the conca d'Oro. In: Maredolce-La Favara. International Carlo Scarpa Prize for Gardens 2015, G. Barbera, P. Boschiero and L. Latini (Eds), Fondazione Benetton Studi Ricerche, Treviso, Italy, 67-87.

Blythe E.K., Sibley J.L., Tilt K.M., Ruter J.M., 2007. Methods of Auxin Application in Cutting Propagation: A Review of 70 Years of Scientific Discovery and Commercial Practice. J. Environ. Hortic. 25 (3), 166-185.

Bowman K.D., Albrecht U., 2017. Efficient propagation of citrus rootstocks by stem cuttings. Sci. Hortic. 225, 681-688.

Bowman K.D., Road S.R., 2018. Weeping Dragon, a unique ornamental citrus. HortScience 53(11), 1708-1710.

Bresc H., 1972. Les jardins de Palerme (1290-1460). Mélanges de l'Ecole française de Rome. Moyen-Age, Temps Modernes 84(1), 55-127.

Bucca M., Zarbà A.S., 2004. The ornamental citrus nursery production in Sicily. Proc. Int. Soc. Citriculture 1, 216-219.

Budiarto R., Poerwanto R., Santosa E., Efendi D., 2017. The potentials of limau (*Citrus amblycarpa* Hassk Ochse) as a functional food and ornamental mini tree based on metabolomic and morphological approaches. J. Trop. Crop Sci. 4(2), 49-57.

Calabrese F., De Michele A., 1995. Il vivaismo agrumicolo ornamentale in Sicilia. Frutticoltura 9, 63-67.

Castle W.S., Bowman K.D., Grosser J.W., Futch S.H., Graham J.H., 2016. Florida citrus rootstock selection guide, 3rd edition. University of Florida, USA.

Carimi F., De Pasquale F., 2003. Micropropagation of Citrus. In: Micropropagation of Woody Trees and Fruits. Forestry Sciences. S.M. Jain, K. Ishii (Eds), Springer, Dordrecht.

Conti F., Fisicaro R., Pedrotti C., Colazza S., 2006. Application of biorational pesticides on nursery trees against *Phyllocnistis citrella* Stainton in Sicily: the effects on different citrus species. Integrated Control in Citrus Fruit Crops. IOBC/WPRS Bull. 29(3), 273-282.

Continella G., La Malfa G., Romano D., 1992. The utilisation of *Citrus* as ornamental plants in Italy. Proc. Int. Soc. Citriculture 1, 232-234.

Crescimanno F.G., Sottile F., 2007. Gli agrumi ornamentali tra arte e scienza. In: Nuove Frontiere dell'arboricoltura Italiana, Gruppo Perdisa Ed., Bologna, Italy, 407-420.

Davino S., Davino M., Sambade A., Guardo M., Caruso A., 2003. The first *Citrus tristeza* virus outbreak found in a relevant citrus producing area of Sicily, Italy. Plant Dis. 87(3), 314.

Del Bosco S., 2003. The use for ornamental purposes of an ancient *Citrus* genotype. Acta Hortic. 598, 65-67.

Dos Santos A.R.A., De Souza E.H., Souza F.V.D., Fadini M., Girardi E.A., Soares Filho W., 2015. Genetic variation of *Citrus* and related genera with ornamental potential. Euphytica 205(2), 503-520.

Dutt M., Stanton D., Grosser J.W., 2016. Ornacitrus: Development of genetically modified anthocyanin-expressing *Citrus* with both ornamental and fresh fruit potential. J. Amer. Soc. Hort. Sci. 141, 54-61.

Dutt M., Nielsen E., Grosser J., 2017. Finger lime could be new crop for citrus growers. Citrus Industry, 1, 22-25.

Eschen R., Britton K,, Brockerhoff E., Burgess T., Dalley V., Epanchin-Niell R., et al., 2015. International variation in phytosanitary legislation and regulations governing importation of plants for planting. Environ. Sci. Policy 51, 228-237.

Eurostat, 2018. Agriculture, forestry and fishery statistics. Statistical Book 2018. European Commission.

Fao Faostat. Food and agriculture data., 2019. http://www.fao.org/faostat/en/. Accessed on line: 15 January 2019.

Gulsen O., Roose M.L., 2001. Lemons: diversity and relationships with selected citrus genotypes as measured with nuclear genome markers. J. Amer. Soc. Hort. Sci. 126, 309-317.

Hodgson R.W. 1967. Horticultural Varieties of Citrus. In: The Citrus Industry. W. Reuther, H.J. Webber and L.D. Batchelor (Eds), University of, Berkeley, CA, USA, 431-459.

Horvath D., 2009. Common mechanisms regulate flowering and dormancy. Plant Sci., 177(6), 523-531.

Kester D.E., 2002. Hartmann and Kester's plant propagation: principles and practices, 7th ed. Pearson Education, USA.

Le Roux S., Barry G.H., 2010. Vegetative growth responses of citrus nursery trees to various growth retardants. HortTechnology 20, 197-201.

Levy Y., Shaked A., Ashkenazi S., 1980. Tree development, yield and leaf nutrient levels of old-clone lemon trees on eight rootstocks. Experim. Agric. (16), 49-55.

Mademba F., Lemerre-Desprez Z., Lebegin S., 2012. Use of Flying Dragon trifoliate orange as dwarfing rootstock for citrus under tropical climatic conditions. Hortscience 47(1), 11-17.

Martínez-Fuentes A., Mesejo C., Muñoz-Fambuena N., Reig C., González-Mas M.C., Iglesias D.J., et al., 2013. Fruit load restricts the flowering promotion effect of paclobutrazol in alternate bearing *Citrus* spp. Sci Hortic-Amsterdam, 151, 122-127.

Mathers H.M., Lowe S.B., Scagel C., Struve D.K., Case L.T., 2007. Abiotic factors influencing root growth of woody nursery plants in containers. HortTechnology 17, 151-162.

Mazzini R.B., Pio R.M., 2010. Morphological characterization of six citrus varieties with ornamental potential. Rev. Bras. Frutic. 32, 463-470.

Morton J., 1987. Calamondin. Fruits of warm climates. Miami, Fl, USA, 176-178.

Mumtaz Khan, M., Azam Khan M., Abbas M., Jaskani M.J., Ali M.A., Abbas H., 2006. Evaluation of potting media for the production of rough lemon nursery stock. Pak. J. Bot. 38(3), 623-629.

Nambuthiri S., Fulcher A., Koeser A.K., Geneve R., Niu G., 2015. Moving toward sustainability with alternative containers for greenhouse and nursery crop production: a review and research update. HortTechnology 25, 8-16.

NeSmith D.S., Duval J.R., 1998. The effect of container size. HortTechnology 8, 495-498.

Nicolosi E., Deng Z.N., Gentile A., La Malfa S., Continella G., Tribulato E., 2000. Citrus phylogeny and genetic origin of important species as investigated by molecular markers. Theor. Appl. Genet. 100(8), 1155-1166.

Ortas I., Ustuner O., 2014. Determination of different growth media and various mycorrhizae species on citrus growth and nutrient uptake. Sci. Hortic. 166, 84-90.

Pagnoux C., Celant A., Coubray S., Fiorentino G., Zech-Matterne V., 2013. The introduction of Citrus to Italy, with reference to the identification problems of seed remains. Veg. Hist. Archaeobot. 22(5), 421-438.

Poole R.T., Conover C.A., Joiner J.N., 1981. Soil and potting mixtures. In: Foliage Plant Production. J.N. Joiner (Ed.), Prentice Hall, Englewood Cliffs., NJ, USA, 179-202.

Ramón-Laca L., 2003. The introduction of cultivated citrus to Europe via Northern Africa and the Iberian Peninsula. Econ. Bot. 57(4), 502-514.

Recupero S., Russo G., Caruso A., Reforgiato Recupero G., Terranova G., 2000. Il vivaismo agrumicolo ornamentale: situazione attuale e attività di ricerca. Riv. Frutticoltura 7, 18-23.

Recupero S., 2009. Agrumi ornamentali. In: Citrus - Trattato di agrumicoltura, Edagricole, Milano. Italy.

Recupero S., Caruso A., Russo G., Reforgiato Recupero G., 2001. Osservazioni sul comportamento di diversi agrumi ornamentali. Riv. Frutticoltura ll, 61-67.

Recupero S., Russo G., Reforgiato Recupero G., 2003a. L'innovazione varietale e tecnologica nel vivaismo agrumicolo ornamentale. Atti Giornate Tecniche SOl "L'innovazione nel vivaismo orto-floro-frutticolo". Taormina (ME) 2-4 October.

Recupero S., Caruso A., Russo G., Reforgiato Recupero G., 2003b. Reale: nuova varietà ornamentale per il vivaismo agrumicolo. Inf. Agr. 26, 51--52.

Recupero S., Russo G., Reforgiato Recupero G., Pietro Paolo D., Caldarera F., 2011. *In vitro* propagation of hybrid candidate rootstocks for ornamental Citrus, Acta Hortic. 892, 301-304.

Recupero S., Russo G., Reforgiato Recupero G., 2015. New promising citrus hybrids for ornamental use. Acta Hortic. 1065, 223-228.

Reforgiato Recupero G., Russo G., Recupero S., 2005. New promising *Citrus* triploid hybrids selected from crosses between monoembryonic diploid female and tetraploid male parents. HortScience 40(3), 516-520.

Rizzo D., Materazzi A., Stefani L., Panattoni A., Pierro R., De Bellis L., et al., 2017. The occurrence of viruses and viroids in ornamental citrus mother plants in Tuscany (Central Italy). Crop Prot. 102, 137-140.

Saleem S.E., Abdel R.A.M., Myhob M.A., 1995. Effect of growing media on growth and leaf mineral content of sour orange rootstock seedlings. Bull. Fac. Agri. University of Cairo 46, 137-147.

Schimmenti E., Di Franco C.P., Galati A., Nartinello S.A., 2009. Aspetti economici del vivaismo agrumicolo ornamentale siciliano. Qanat-Editoria e Arti Visive, Palermo, Italy.

Scora R.W., 1975. On the history and origin of Citrus. Bull. Torrey Bot. Club 102, 369-375.

Siragusa M., De Pasquale F., Abbate L., Martorana L., Tusa N., 2008. The genetic variability of Sicilian lemon germplasm revealed by molecular marker fingerprints. J. Amer. Soc. Hort. Sci. 133, 242-248.

Sottile F., De Pasquale F., 2012. Agrumi ornamentali. In: AA.VV. Gli Agrumi. Bayer CropScience. E. Tribulato and P. Inglese (Eds), Script, Bologna, Italy.

Srivastava A.K. 2012. Integrated nutrient management. In: Advances in Citrus Nutrition. A.K Srivastava (Ed.), Springer, Verlag, The Netherlands, 369-389.

Tadeo F., Cercós M., Colmenero-Flores J., Iglesias D., Naranjo M., Rios G., et al., 2008. Molecular physiology of development and quality of *Citrus.* Adv. Bot. Res. 47, 147-223.

Tolkowsky S., 1938. Hesperides, a history of the culture and use of Citrus fruits. J. Bale & Curnow, London, UK.

Torrisi B., Recupero S., Caldarera F., Allegra M., Intrigliolo F., 2004. Comparison between different growing substrates for the ornamental citrus trees. Proc. Int. Soc. Citriculture Congress. Agadir, Morocco, 15-20 February, 220-222.

Uzun A., Gulsen O., Kafa G., Seday U., 2015. New lemon genotype for ornamental use obtained from Gamma irradiation. Acta Hortic. 1065, 245-247.

Wearn J.A., Mabberley D.J., 2016. Citrus and Orangeries in Northern Europe. Curtis's Bot. Mag. 33, 94-107.

Webber H.J., 1967. History and development of the Citrus industry. In: The Citrus Industry. W. Reuther. et al. (Eds) Vol. 1, University of California, Berkeley, USA.

Wu G.A., Terol J., Ibanez V., López-García A., Pérez-Román E., Borredá C., et al., 2018. Genomics of the origin and evolution of *Citrus*. Nature 554, 311-316.

Zekri M.R., Koo C.J., 1992. Use of controlled-release fertilizers for young citrus trees. Sci. Hortic. 49, 233-241.

Received December 4, 2018; accepted April 15, 2019