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Fruit Industry

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Contributors
Mateus Pereira Gonzatto, Sabrina Raquel Griebeler, Sergio Francisco Schwarz, Ibrahim Kahramanoglu, Chunpeng Wan, Serhat Usanmaz, Oluyinka Adewoyin, Folasayo Fayose, Lydia Babatola, Anthony Ekeocha, Temidayo Apata, Adebayo Ibidapo, Murat Helvaci, Juan Manuel Covarrubias-Ramírez, Juan Guilermo Martinez-Rodriguez, Victor Manuel Parga-Torres, Pranas Viškelis, Ieva Urbanaviciute, Monia Ben Halima Kamel, Lassaad Mdellel, Rihem Adouani

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Chapter 4

Dwarfing Rootstocks for High-Density Citrus Orchards

Mateus Pereira Gonzatto, Sabrina Raquel Griebeler and Sergio Francisco Schwarz

Abstract

There is a worldwide trend regarding high density of fruit planting. In the last four decades, the Brazilian citriculture had increased the average planting density by more than 80%. The main reasons for this increase are the fast return on invested capital, the easiest management of cultural practices, and the control of strategies epidemics-associated (e.g., *Huanglongbing*). In that regard, the use and development of dwarf and semi-dwarf rootstocks are essential. The main dwarf rootstock known in citriculture is the Flying Dragon trifoliate orange [*Poncirus trifoliata* (L.) Raf. var. *monstrosa* (T. Itô) Swing.] which greatly reduces the canopies volume allowing the design of dense and ultra-dense orchards. Currently, several citrus breeding programs are producing new cultivars of dwarf and semi-dwarf rootstocks. In this chapter, citrus rootstocks with dwarfing potential were approached including physiological aspects, horticultural performance, and behavior to phytosanitary problems. In addition to Flying Dragon, there are other dwarfing rootstocks which are hybrids of trifoliate oranges, like citrandarins, citrangedarins, citrumelandarins, and citrimoniananda-rins. Dwarfing rootstocks are one of the leading alternatives for citrus orchards in high-density planting systems.

Keywords: *Poncirus trifoliata* Raf., *Citrus* spp., Flying Dragon trifoliate orange, citrandarin, citrangedarin, citrumelandarin

1. Introduction

The high-density planting allows an increase in fruit yield per area in the initial years of production and a reduction in the payback period despite the higher cost of implementing the orchards. Therefore, it has been a trend to enhance the production system [1, 2]. Moreover, high-density planting improves orchard harvesting since there is no need for ladders [3, 4], and also reduces loss by diseases such as *Huanglongbing* (HLB) [5]. However, this technology requires effective control of the canopy growth of citrus plants. A suitable planting density with restricted space available for the growth of these plants and avoidance of excessive intercrossing of scions must be employed [3].

In Southeast Brazil, citrus orchards have shown an increase in planting densities, from an average of 337 trees per hectare in the 1980s to over 600 trees per hectare

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since 2013. Since 2014, a stabilization in planting densities of around 650 trees per hectare is noted [6].

Two main classifications of citrus plants size are proposed. To Castle and Phillips [7], a classification was recommended according to the height or volume of scions into four categories regarding a standard plant: dwarf, semi-dwarf, semi-standard, and standard. Dwarf and semi-dwarf occur when the plant is 40% and 40–60% of the standard size, respectively. Semi-standard arises to plant with a size of 60–80% of the standard. Standard, on the other hand, is used for plants having 80–100% of the standard size. In this classification, the standard used was plants grafted onto a rough lemon (*Citrus jambhiri* Lush.). Another classification was proposed by Bitters et al. [8] in which a tree with a height of 6.0 m or more was used as the standard. Sub-standard plants, semi-dwarf plants, and dwarf plants were the ones which have a reduction of 25%, 50%, and 75%, respectively regarding the standard.

Many factors affect citrus plants' size such as rootstock, variety, soil and climate conditions, cultural treatments, and phytosanitary conditions [3]. The effective control of the citrus growth plants can be achieved by means of several strategies: (a) use of scions with restricted growth potential; (b) pruning; (c) biological agents, usually viroids and viruses; (d) restriction of the root system growth; (e) use of dwarfing, semi-dwarfing and intergrafted rootstocks; (f) sloping planting of seedlings, and (g) use of plant growth regulators [3, 9]. Among them, probably the most effective is the use of dwarfing rootstocks [7] because few scion varieties have significantly reduced growth by themselves. In mandarin trees, some cultivars of the Satsuma group (*Citrus unshiu* Marcovitch) such as 'Clausellina' and 'Hashimoto' are highlighted due to their small growth [10].

This chapter presents the most important rootstocks for citrus high-density orchards in addition to the most recent alternatives. The main characteristics and horticultural performance of rootstocks were approached.

2. Dwarfing rootstocks and high-density citrus orchards

A dwarfing rootstock is the one that in combination with any canopy genotype, generates a mature tree with a height of no more than 2.5 m, independent of environmental and/or viral influences [11]. Currently, several materials from directed hybridization are classified as dwarfing. Nevertheless, few of them seem to provide an increment in the trees yield efficiency. Diversely, Flying Dragon [*P. trifoliata* (L.) Raf. var. *monstrosa* (T. Itô) Swing.] had a high yield efficiency [12–16] probably due to distinct dwarfing mechanisms [17].

In Brazil, densified citrus orchards have densities between 600 and 1250 plants ha^{-1}, with distances of 4–6 m between rows and 2–3 m between plants [2, 5]. Differently, ultra-dense orchards are those where planting densities vary from 1500 to 2000 plants ha^{-1}. Theoretically, these ultra-dense-orchards reach up to tens of thousands of trees per hectare, within the concept of "meadow orchard" [9]. In recent work in India with Nagpur mandarin onto Rangpur lime, a high-density was considered as the one bearing between 555 and 625 plants ha^{-1} and an ultra-high density planting the one varying from 1250 and 2500 plants ha^{-1} [18]. In Japan, long-term experiments were accomplished in 'Wase' satsuma mandarin (*C. unshiu* Marc. var. *praecox* Tan.) to evaluate orchards with densities of up to 10,000 plants ha^{-1} [19, 20].

Densification is a common practice in mandarin orchards in Southern Brazil. There is a spacing recommendation for *P. trifoliata* varying from 6.5 m × 3.0 m to 5.0 m × 2.0 m (512–1000 plants ha^{-1}), depending on soil fertility. For mandarin plants grafted onto Flying Dragon, a spacing of 4.5 m × 1.5 m and 4.0 m × 1.0 m (1480 and 2500 plants ha^{-1}) is recommended in high and low fertility soils, respectively [21]. In Southeast Brazil, row spacing of 4–5 m and plant spacing of 1.5–2.5 m is recommended for the Flying Dragon rootstock [22]. In Florida, despite its limited commercial use, a spacing of 5–7 ft (1.52–2.13 m) is recommended between plants grafted onto Flying Dragon. Instead, for common trifoliate orange, there is a spacing recommendation of 6–8 ft (1.83–2.44 m) [23].

In Iran, three planting spacings/densities were evaluated on 'Unshiu', 'Clementina', 'Page' and 'Ponkan' mandarin grafted onto Flying Dragon (4 m × 4 m, 625 plants ha^{-1}; 4 m × 3 m, 833 plants ha^{-1}; and 4 m × 2 m, 1250 plants ha^{-1}). There was no effect of planting density on yield per plant. Nevertheless, yield per area increased significantly at the highest planting density. 'Ponkan' mandarins showed a better yield performance, while 'Page' mandarins had the worst yield performance and the lowest growth in the first five productive years of the orchard [22]. In later studies, the mandarin tree 'Span Americana', an early variety from the same group as 'Ponkan', performed well over Flying Dragon. Then, it has shown potential for densely planted orchards [23]. Furthermore, reports indicate a better performance of densified systems in citrus plants having columnar canopies.

Biological agents are also explored in citrus high-density planting toward the re-engineering of citrus seedlings. As recently shown, the use of Citrus dwarfing viroid (CDVd) into trifoliate orange rootstock 'Rich 16-6' (*P. trifoliata* (L.) Raf.) reduced canopy volume by up to 50% [24]. Beyond size reduction, the canopy of CDVd-infected trees had a long-lasting phenotype regarding Flying Dragon rootstock. Further, a report aimed to discover the mechanism of CDVd dwarfism. The understanding of this mechanism would allow the development of commercial products absent infectious agents [25].

2.1 Flying Dragon trifoliate orange

The most important and well-established citrus dwarfing rootstock is the Flying Dragon trifoliate orange, also known as Hiryu or Japanese Hiryo [26–28]. The Flying Dragon [*P. trifoliata* var. *monstrosa* (T. Itô) Swing.] originated as a mutant of a non-dwarfing trifoliate orange [*P. trifoliata* (L.) Raf.]. Besides, it has not undergone sexual recombination suggesting a great degree of kinship between *P. trifoliata* and Flying Dragon genotypes [29, 30].

A large number of studies over Flying Dragon rootstock in several environments and with many citrus scions are reported [4, 12–16, 22, 23, 26, 28, 31–37]. Due to the several advantages, it is an interesting alternative for densification of citrus orchards [28], mainly for 'Tahiti' lime [35] and mandarins [22].

The trees grafted onto Flying Dragon rootstock are small or dwarf sized, with a maximum height between 2.5 and 3.0 m [26, 28]. Flying Dragon features curved thorns and tortuous trunk, unlike common trifoliate orange (**Figure 1**). These two characteristics are morphological markers of the dwarfing effect, due to gene linkage or pleiotropy [29]. The tortuosity inheritance seems to be linked to three nuclear genes (Cr1, Cr2 and Cr3), in which the Flying Dragon genotype is entirely heterozygous (Cr1cr1Cr2cr2Cr3cr3), with seedlings of tortuous phenotypes showing

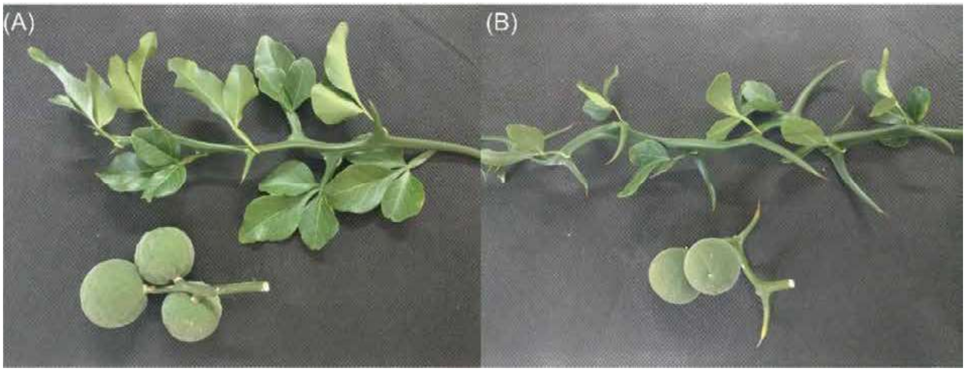

Figure 1.
*Fruit and branches of trifoliate oranges. (A) common trifoliate orange (*P. trifoliata*); (B) Flying Dragon trifoliate orange (*P. trifoliata *var.* monstrosa*).*

low canopy growth, while the phenotypes with straight structures showed a great variability [27].

As there is a great genetic proximity between Flying Dragon and the trifoliate orange, they have many similar characteristics [10]; excellent fruit quality of the scion variety [38], late maturation, tolerance to cachexia, and sudden death. They are also resistant to the nematode *Tylenchulus semipenetrans* as well as to *Citrus tristeza* virus and to citrus gummosis (*Phytophthora* spp.). Beyond, both rootstocks are susceptible to citrus decline, exocortis, and burrowing nematode (*Radopholus similis*) as well as a high tolerance to cold and waterlogging and low tolerance to drought [39–41]. Further, HLB incidence on Flying Dragon is lower than on Rangpur lime and the other three semi-standard rootstocks. The reduction in canopy volume seems to influence host–vector relationships [42].

Furthermore, incompatibilities between *P. trifoliata* and several canopies such as: ‘Pêra’, ‘Rio Seleta’ and ‘Crescent’ orange; ‘Murcott’ tangor; ‘Sicilian’ and ‘Eureka’ lemon are described [40, 41, 43]. There are also incompatibilities in Flying Dragon under ‘Lima-da-Persia’ [*Citrus limettioides* (Christm.) Swingle] and kumquat (*Fortunella* sp.) in South Brazil [44]. In Spain, there is a record of incompatibility when the scion is 'Eureka' [10].

In Brazil, there are five cultivars registered as *P. trifoliata* var. *monstrosa* (T. Itô) Swing. in the Ministry of Agriculture, Livestock and Supply (MAPA). Cultivars were also registered by other agricultural Brazilian institutes. Two were registered by the Agronomic Institute of Campinas (IAC, ‘IAC 848 Davis A’ and ‘IAC 718 Flying Dragon’). One cultivar was registered by the Agriculture Research and Extension Agency of Santa Catarina State (EPAGRI, ‘Flying Dragon’) and by the Rural Development Institute of Paraná (IAPAR-EMATER, ‘IPR 150’). Additionally, the 'Citrolima Flying Dragon' is also registered [45].

Flying Dragon has some disadvantages, like the low nucellar polyembryony, requiring a very strict selection of seedlings to be grafted [46–48]. Besides that, this rootstock has seed germination and seedling uniformity between 80 and 90% [39]. It requires a longer period for commercial seedling formation than other rootstocks, mainly in low-temperature climates [49]. It is also a drought-sensitive dwarf rootstock [13], requesting a regular rainfall distribution. If the region has a well-defined dry period, irrigation is needed [50]. Nevertheless, under non-irrigated conditions and in soil without chemical restrictions, Tahiti lime grafted onto Flying Dragon

(1157 plants ha^{-1}) and grown in a no-till system intercropped with *Urochloa ruziziensis* developed higher fruit production in the first 5 years. Apart from that, Tahiti limes grafted on Flying Dragon also showed reduced water stress, a better soil chemical and physical characteristics regarding tilled orchards [51].

The use of trifoliate oranges as rootstock demands specific soil fertility conditions, because of its high demand for nutrients [52]. These rootstocks have restrictions on the presence of toxic aluminum in the soil solution, and consequently, a restriction to acidic soils not corrected with liming [53]. With regard to Flying Dragon, there is poor performance in basic pH soils [39] due to the high requirement for iron [52]. Unlike plants of Citrus genus which have few or no root hairs under field conditions, trifoliate oranges can develop root hairs when grown in sand culture [54].

Flying Dragon is employed to Satsumas mandarins culture (*C. unshiu*) in protected structures of Japanese regions and in the southern United States [55]. In Southeast Brazil, it was used in 3% of total citrus seedlings produced in 2020, mostly to produce seedlings of 'Tahiti' lime (*C. latifolia)* [52], allowing planting densities of up to 2500 plants ha^{-1} [35]. Hence, in the first 3 productive years of the orchard, an increase in scions volumes and of the yield at the highest densities was observed [35]. For 'Tahiti' lime under irrigated conditions, there was a reduction in the yield efficiency regarding non-irrigated conditions. This lower yield efficiency is associated with an increase of more than 70% in scion volume due to irrigation [37].

In New Caledonia [28], the economic performance of 'Tahiti' orchards over 13 years under two installation conditions were compared: a high-density planting where trees were grafted onto Flying Dragon and a conventional orchard, where trees were grafted onto 'Volkamer' lemon. For high-density planting, the density was set at a rate of 1000 trees ha^{-1} while for the conventional orchard the density was 208 plants ha^{-1}. The installation cost of the densified orchard was 2.6-folds higher than the conventional orchard because of the higher seedling cost and the planting labor. However, the recovery of invested capital occurred in 4 years for the densified orchard and in seven years for the conventional orchard. Furthermore, the cost of production was US$ 0.30 and US$ 0.57 per kg of fruit produced in the high-density plantation and conventional plantation, respectively. Therefore, the high-density orchard generated over 13 years a gross revenue 3.3-folds higher than a conventional orchard. In contrast, densified conditions with mechanical pruning seem to be inappropriate for 'Valencia' orange, 'Hamlin' orange, and 'Murcott' tangor (2020 plants ha^{-1}) due to the small yields obtained [31].

Another option for Flying Dragon use is as an interlock to modulate vegetative growth. Nevertheless, there is a strong interaction with the rootstock and scion varieties employed. When intergrafted between rootstocks such as 'Swingle' citrumelo or sour orange, or scions as 'Star Ruby' grapefruit (*C. paradisi*) or 'Michal' mandarin (*C. clementina* × *C. tangerina*), Flying Dragon seems to reduce the vegetative growth [56]. On the other hand, when intergrafted under 'Tahiti' lime, the effect depends on the rootstock. A reduction in scion was observed when Flying Dragon was grafted onto 'Catania 2' Volkamer lemon (*Citrus volkameriana* Ten. & Pasq.). Oppositely, an increase in vegetative growth was seen when it was grafted onto *P. trifoliata* 'Davis A'. No effect on scion size was noticed when the Flying Dragon was grafted onto 'Morton' citrange and onto the 'Swingle' citrumelo [37].

Orange "Navelina" and lemon 'Kütdiken' plants intergrafted on Flying Dragon using sour orange as rootstock had 41.1% and 22.5% of growth reduction compared to non-intergrafted plants, respectively. In parallel, during winter and spring, the presence of the intergraft increased net CO_2 assimilation for both canopies. To Navelina orange trees, an increase in transpiration was also observed [57]. In 'Mexican' lime trees onto Alemow (*Citrus macrophylla*) rootstock, the use of Flying Dragon interstocks reduced the canopy volume by more than 60%. Then, there is the maintenance of fruit yields at commercially acceptable volumes (80 kg ha^{-1} ano^{-1}). Also, this would be a viable approach for regions with HLB endemic occurrence [58].

As regards to dwarfing mechanism, the canopies grafted on the Flying Dragon trifoliate tree had a reduced sap flux compared to plants grafted on common trifoliate orange [38]. In comparison to common trifoliate trees, the Flying Dragon reduced the hydraulic conductivity of rootstock and of graft union regions. Further, a restriction of carbohydrate flow to the roots through the grafting region was described [59]. Besides, Flying Dragon had stem and roots xylem vessels larger as well as a lower phloem percentage than the vigorous rootstock Rough lemon (*C. jambhiri)* [60]. The lower carbohydrate flow through the grafting region to the roots supports the reduced root system and the increased production efficiency, expressed in mass of fruit per unit of canopy volume. Additionally, there was a reduction in net CO_2 assimilation, of stomatal conductance. A reduction of transpiration between 12:00 and 3:00 p.m in plants grafted onto Flying Dragon compared to those onto common trifoliate orange was noted [59].

Phytohormones have different behaviors on dwarfing and vigorous rootstocks. The highest indolacetic acid (IAA) level was found in 'Eureka' lemon new shoots on 'Swingle' citrumelo and the lowest was found on Flying Dragon. Opposite effects were seen to abscisic acid (ABA). Higher content of ABA was seen in 'Eureka' lemon new shoots on Flying Dragon while lower ABA content was observed on 'Swingle' citrumelo. An assumption is that higher ABA levels account for plant growth reduction [61]. Likewise, the exogenous use of gibberellic acid and inhibitors of its synthesis are involved in the control of vegetative growth in citrus [62, 63].

Recently, *P. trifoliata* as a rootstock displays a potentiality to increase DNA demethylation and the amount of *24-nt small RNAs* on the orange scion compared to *P. trifoliata* grafted onto itself [64]. The evidence of possible epigenetic modifications imparted by grafting may also be associated with the mechanism of rootstock dwarfing.

2.2 Others dwarfing rootstocks

Several rootstocks are classified as dwarfing: 'Cunningham' and 'Yuma' citranges, 'Cuban' pummelo, *Citrus ichangensis*. Besides, other species belonging to the Rutaceae family, such as the genus *Hesperetusa, Citropsis, Clymenia, Eremocitrus e Microcitrus* have also a dwarfing effect [8, 26]. Nonetheless, in many cases, the dwarfing effect is not fully established. It is not clarified whether this effect is due to the rootstock effect itself, to the environment interaction with viral agents, or even to difficulties linked to rootstock/scion incompatibility [26].

In Spain, two dwarfing rootstocks developed by IVIA (The Valencian Institute of Agrarian Research) highlighted: Forner-Alcaide (FA) 418 and FA 517. The rootstock FA 418 is a citrangedarin, a hybrid of Troyer citrange (*C. sinensis* × *P. trifoliata*) with common mandarin (*Citrus deliciosa* Ten.). FA 517, is a citrandarin (*Citrus nobilis* Lour × *P. trifoliata*). Both rootstocks provided a large reduction in canopy volume and a significantly increase in yield efficiency of Navel orange compared to 'Carrizo' oranges. Along with that, both rootstocks induced the production of good quality fruit, with FA 517 inducing early entry into production. On pioneers roots (diameter 2–4 mm), FA 517 had a higher frequency of xylem vessels with diameters greater than 30 μm, while FA 418 showed higher densities of xylem vessels. These rootstocks reduced the hydraulic conductance, the net CO_2 assimilation, the stomatal conductance, and the transpiration. A greater reduction was noticed in Navel orange over FA 418 [65]. Yet, the rootstocks were tested under ultra-high-density conditions, between 1250 and 3333 plants ha^{-1}, and with mechanical harvesting (over-row continuous canopy shaking harvester) [66, 67]. Additionally, FA 517 exhibited resistance to Citrus tristeza virus, to *Phytophthora* sp. gummosis, and to nematode *Tylenchulus semipenetrans.* More, a good performance in saline and clayey soils resulting in high fruit yields beheld. On the other hand, FA 418, induced a greater reduction of tree size. Although larger fruits were obtained, they were more susceptible to the nematode *Tylenchulus semipenetrans* and to *Phytophthora* gummosis. Advantageously, FA 418 is tolerant to *Citrus tristeza* virus [68].

In USA, rootstock US-897 citrandarin was released by the US Department of Agriculture with the goal of reducing the size of plants in high-density orchards. His rootstock is used on 7% of the citrus orchards in Florida to high-density plantings in field and in protected structures. US-897 rootstock is a cross of Cleopatra mandarin (*C. reshni* Hort. ex Tan.) × Flying Dragon trifoliate orange (*P. trifoliata*). The yield of trees grafted onto US-897 is low. Nonetheless, due to the small size of the trees, calculations of the potential yield per hectare at the predicted optimum spacing can be very high. Despite the fruit good internal quality of US-897, its size can often be below average. It has tolerance to *Citrus tristeza* virus, citrus nematodes, the *Phytophthora–Diaprepes* complex, and high pH [69]. In-row spacings of 8 and 10 ft (2.42 and 3.05 m) are recommended for this rootstock [39].

Farther, new rootstocks have been produced by the University of Florida breeding program. Many of them are tetraploids, somatic hybrids, or sexual hybrids of two somatic hybrids. Among them, citrandarin UFR-6 (*C. reticulata* 'Changsha' + *P. trifoliata* '50-7') is a candidate for high-density plants, producing small plants, cold-hardy plants, and fruits with high soluble solids content [69, 70]. Beyond that, it is tolerant to *Phythophtora* gummosis and to *Citrus tristeza* virus. Plant spacing between 6 and 8 ft (1.83–2.44 m) is recommended [39].

Table 1 summarizes the characteristics of rootstocks discussed so far: Trifoliate orange, Flying Dragon, FA 148, FA 517, US 897, and UFR 06. In this table, aspects related to horticultural performance and biotic and abiotic stresses are compiled.

In Brazil, the citrus breeding program of EMBRAPA (Brazilian Agricultural Research Corporation) has developed rootstocks by hybridization. Among the genotypes tested for the 'Valencia' orange, four are important with respect to dwarfing effect along with relatively high fruit yield, high yield efficiency, and good fruit quality. These rootstocks are three citrandarins (TSKC × TRFD-003, TSKC × TRFD-006, TSKC × TRFD-007) and one citrumelandarin (TSKC × CTSW-058), hybrids of Common Sunki mandarin [*Citrus sunki* (Hayata) Hort. ex Tan.] with Flying Dragon trifoliate orange [*P. trifoliata* var. *monstrosa* (T. Itô) Swing.] or with Swingle citrumelo (*C. paradisi* Macfad. × *P. trifoliata*). Apart from that, TSKC × TRFD-003 citrandarin had a similar drought tolerance to Santa Cruz Rangpur lime (*Citrus limonia* Osbeck) [71]. Also, in the 'Valencia' orange several other materials seem to have dwarfing potential. Among them, the TSKC × (LCR × TR)-059 citrimoniandarin had a high yield efficiency, a dwarfing effect, an induction of earlier fruit-bearing with higher quality, and good drought tolerance [72, 73].

In other experiments with 'Valencia' orange in southeast Brazil, tetraploid Swingle citrumelo had a dwarfing performance which reduced canopy volume by 77% compared to the vigorous standard. In this same experiment, citrandarins offspring of Flying Dragon had no dwarfing behavior [74]. In 'Tahiti' lime, TS × PT 14 citrandarin had a dwarfing behavior and potential tolerance to HLB [75].

Features	Trifoliate orange	Flying Dragon	FA 148	FA 517	US 897	UFR 06
Horticultural performance						
Yield per tree	L-I	L-I	I	H	L	H
Yield efficiency	I-H	H	H	H	H	H
Earl bearing	I	I	I	H		
Fruit size	Sm-I/L*	Sm-I/L*	Lg	I-Lg	Sm-I	Sm-I
Fruit quality	H	H	H	H	H	H
Maturity	I	I				
Abiotic stress						
Drought stress	P	P				
Salinity	P	P	G	I-G		[I]
Flooding	I	I				
Freeze	G	G			[I]	G
Soil high-pH	P	P	G	G	[I]	
Soil low-pH	P	[P]				
Biotic stress						
Tristeza	T	T	T	R	T	T
Phytophthora	T	T	S	T	T	T
Nematode	T	T	S	R		

[a]*Sm–small; L–low; I–intermediate; Lg–large; H–high; P–poor; G–good; R–resistant; S–susceptible; T–tolerant. [ ] - Any symbol in brackets indicates a probable or expected behavior.*
**Conflicting data in the literature.*

Table 1.
Main features of dwarfing citrus rootstocks and common trifoliate orange (a semi-dwarfing rootstock) [39, 52, 68][a].

Other dwarfing rootstocks are also approached. In hot arid climate in India, Fremont mandarin had dwarfing behavior when grafted on *Citrus pectinifera*, probably a *Citrus depressa* Hayata, compared to vigorous rootstocks (Karna khatta and Rough lemon) [76]. In China, hybrids of Ziyang Xiangcheng (*Citrus junos* Sieb. ex Tan.) and trifoliate orange (*P. trifoliata*) were researched and ZZ6, ZZ31, and ZZ948 rootstocks showed strong alkaline tolerance (pH 8.2). Among these hybrids, ZZ6 and ZZ948 were rootstock dwarfing type [77].

There are several potentially dwarfing rootstocks that have emerged in recent decades from worldwide breeding programs. Nevertheless, the confirmation of these potentials needs further investigations. In those investigations, it is required the evaluation of these materials under different scions and at different environments for a minimum period of time, to generalize this information [78].

3. Conclusions

Citrus dwarfing rootstocks are the main options to enable the development of designed orchards in high and ultra-high density planting systems allowing easy mechanical harvesting and cultivation under protected structures. Further, it is paramount to perform a regional studies of different dwarf rootstocks genotypes and their interaction with the different scions as well as economic feasibility. With a well-conducted and designed studies, it is possible to establish recommendations and guide the correct management of dense citrus orchards in different environments. Therefore, the reduction of plant growth provided by rootstocks can be a management strategy to improve the orchard horticultural performance.

Author details

Mateus Pereira Gonzatto[1]*, Sabrina Raquel Griebeler[2] and Sergio Francisco Schwarz[2]

1 Department of Agronomy, Federal University of Viçosa, Viçosa, Brazil

2 Department of Horticultural Sciences and Forestry, Federal University of Rio Grande do Sul, Porto Alegre, Brazil

*Address all correspondence to: mateus.gonzatto@ufv.br

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