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Stuchi, Eduardo Sanches; Girardi, Eduardo Augusto; Silva, Simone Rodrigues da; Cantuarias-Avilés, Tatiana; Parolin, Luiz Gustavo; Reiff, Eduardo Toller; Sempionato, Otávio Ricardo

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CROP PRODUCTION AND MANAGEMENT - Article

Satsuma mandarins grafted onto Swingle citrumelo for early season harvest in subtropical conditions in Brazil

Eduardo Sanches Stuchi[1]*, Eduardo Augusto Girardi[2], Simone Rodrigues da Silva[3], Tatiana Cantuarias-Avilés[3], Luiz Gustavo Parolin[1], Eduardo Toller Reiff[1], Otávio Ricardo Sempionato[1]

1.Estação Experimental de Citricultura de Bebedouro - Bebedouro (SP), Brazil.
2.Embrapa Mandioca e Fruticultura - Cruz das Almas (BA), Brazil.
3.Escola Superior de Agricultura Luiz de Queiroz - Departamento de Produção Vegetal - Piracicaba (SP), Brazil.

ABSTRACT: Although Brazil is the sixth producer of mandarins in the world, fresh fruit exports are neglectable, and few cultivars are available for the domestic market. Main harvest season comprises May to November, with Ponkan mandarin and Murcott tangor representing more than 70% of the production. Therefore, there is a need for alternative early season, seedless varieties that should also be preferably resistant to Alternaria brown spot. We investigated the horticultural performance of ten selections of Satsuma mandarin in subtropical conditions in Bebedouro, northern state of São Paulo, Brazil. Clausellina, Okitsu, Unshu SRA-529, Saigon SRA-227, Panaché SRA-579, Salzara SRA-341, Miyagawa SRA-444, Kowano SRA-167, FCAV-59 and A2 60.0 selections were grafted on Swingle citrumelo and evaluated up to 7 years old. Unshu, Miyagawa and A2 60.0 presented the highest tree size. These three selections, in addition to Okitsu and Kowano mandarins, resulted in higher fruit yield for the five first harvests (mean of 31.3 $kg \cdot tree^{-1} \cdot year^{-1}$). Panaché had the smallest yield efficiency. Miyagawa and A2 60.0 selections presented lower alternate fruit bearing in the evaluated period due to their early bearing habit. These same selections had the largest fruits with the earliest maturation; similar to the Okitsu mandarin, but with lower soluble solids and higher juice content. The overall performance of the Satsuma mandarin selections grafted on Swingle citrumelo and drip irrigated was promising under subtropical climate. The Okitsu, Miyagawa and A2 60.0 mandarins were selected because of their highest productive potential and their valuable quality traits for the Brazilian domestic market.

Key words: *Citrus unshiu*, *Citrus paradisi* × *Poncirus trifoliata*, fresh fruit, fruit maturation, variety diversification.

*Corresponding author: stuchi@estacaoexperimental.com.br

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INTRODUCTION

The global production of mandarins and related fruits in 2016 reached approximately 32.8 million t (FAO 2018), with Brazil occupying the sixth position in the world production rank, with nearly 1,000,000 t harvested from approximately 50,000 ha. The state of São Paulo is the leading producer, accounting for 35% of the national production (IBGE 2016).

Ponkan mandarin (*Citrus reticulata* Blanco) is the most planted cultivar in Brazil followed by Murcott tangor (*C. reticulata* × *C. sinensis* (L.) Osbeck) and, in smaller proportions, by both Cravo (*C. reticulata*) and the Mediterranean or Willow-leaf mandarin (*C. deliciosa* Tenore) (Pio et al. 2005). The Ponkan mandarin is harvested from May to July, while Murcott tangor is picked from August to November, with a well-defined off-season for the internal market. Both cultivars are seedy and susceptible to Alternaria brown spot caused by *Alternaria alternata*, especially the Murcott tangor which, in addition, is more difficult to peel, but has better shelf life than the Ponkan mandarin (Solel and Kimchi 1997; Peres et al. 2003; Pio et al. 2005; Souza et al. 2009; Azevedo et al. 2015).

Satsuma mandarins (*C. unshiu* Marcovitch) were originated in Japan (Hodgson 1967), where they are highly prized for their delicate and very early seedless fruits and their good adaptation to the Cfa (subtropical humid) Japanese climate. Although over 200 citrus cultivars have been licensed for cultivation since 1981 in Japan, Satsuma mandarin is still the main cultivated group, accounting for 62% (45.500 ha) of all the citrus acreage (72.600) in 2014 (Fujii et al. 2016). In Spain, Satsuma mandarins cover around 6% of the mandarin growing area, in contrast to China, where more than 40% of the mandarin orchards have Satsuma varieties (Garcia-Sanchez et al. 2016). In 2016, the total Satsuma production in Spain was 213,411 t (MAPA 2017).

Satsuma mandarins are also of relative commercial importance in the United States (Campbell et al. 2004). The northern coastal fringe of the Gulf of Mexico, extending from Louisiana to northwestern Florida, is particularly well suited for the production of Satsuma mandarins, and there is an increasing interest in this cultivar in this region (Spiers et al. 2017; Andersen and Brodbeck 2015).

In Brazil, the main planted area with Satsuma mandarins is in Rio Grande do Sul state (around 110 ha) with Okitsu being the most used cultivar. In Paraná and São Paulo states, Satsumas are restricted to small orchards, where the Okitsu cultivar is the leading cultivar (Tazima et al. 2013; 2014). Okitsu is a seedless, easy to peel, early maturing cultivar, highly productive and resistant to limiting diseases, such as citrus canker, Alternaria brown spot and citrus variegated chlorosis (Silva et al. 2009; Reis et al. 2007; Souza et al. 2009; Tazima et al. 2014; Fujii et al. 2016). Donadio et al. (1998) reported a harvesting season from January to March for Okitsu and Clausellina mandarins in São Paulo state, although their fruits can eventually be stocked on the trees until late April and May in northern state of São Paulo (Silva et al. 2009). Therefore, the cultivation of this group of mandarins is arousing high commercial interest in Brazil.

Okitsu mandarin grafted onto several rootstocks has been evaluated in Paraná (Tazima et al. 2014) and São Paulo states (Cantuarias-Avilés et al. 2010), where Swingle citrumelo (*C. paradisi* Macfad. cv. Duncan × *Poncirus trifoliata* (L.) Raf.) proved to be a fair rootstock. Okitsu was studied and recommended for cultivation in the state of Rio Grande do Sul, southern Brazil (Oliveira et al. 2005; Oliveira and Scivittaro 2011; Teixeira et al. 2017), and could be therefore considered as the standard Satsuma mandarin in Brazil. Nonetheless, only one study has been published on fruit quality of other selections of this mandarin (Silva et al. 2009).

In this context, the horticultural performance of ten selections of Satsuma mandarin grafted onto Swingle citrumelo was evaluated under subtropical climatic conditions in northern São Paulo state, Brazil. We aimed to select alternative mandarin varieties for the production of high-quality fruits in the early season for the domestic market.

MATERIAL AND METHODS

The experiment was carried out in Bebedouro, at the northern region of São Paulo state, Brazil (20°53'16" S, 48°28'11" W, 601 m Altitude). Meteorological variables were computed during the harvesting period (Fig. 1). The soil was a deep, dark red oxisol, eutrophic, endoalic, moderate A horizon and with clayey texture (38% clay), with no physical or chemical restrictions (pH ($CaCl_2$) = 5.1; CEC = 56.3 $mmol_c \cdot dm^{-3}$ in the 0–20 cm of the upper →

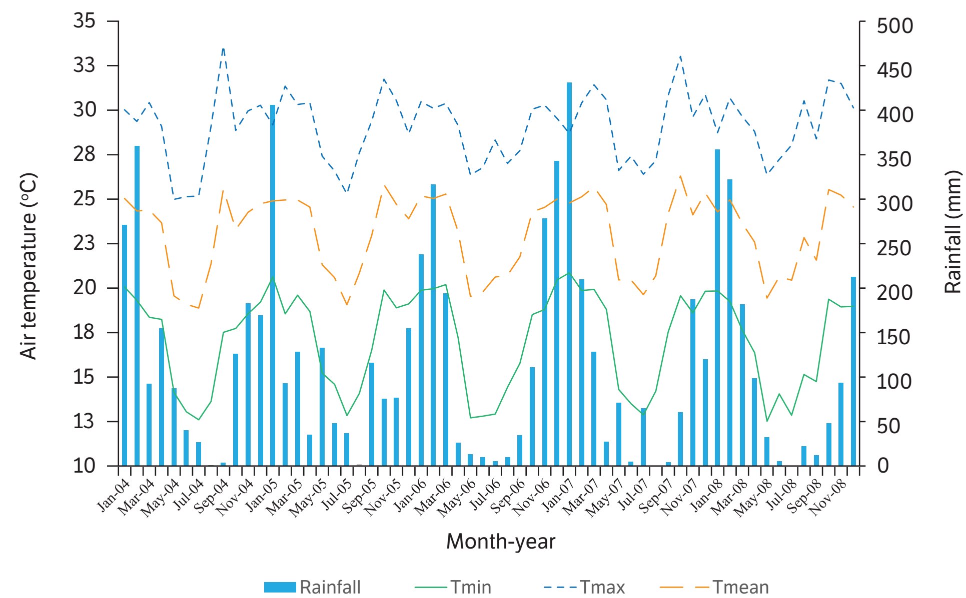

Figure 1. Monthly rainfall and average air temperature (maximum, minimum and mean) from 2004 to 2008 (first to fifth harvest) of ten Satsuma mandarin selections grafted on Swingle citrumelo at the Citrus Experimental Station in Bebedouro, northern São Paulo state, Brazil. Data obtained from a Campbell Scientific, Logan, USA, automated meteorological station, model CR10.

surface of the soil layer) (Embrapa, 2013). This type of soil is commonly planted with commercial citrus orchards in this region, as well as other oxisoils and argisoils (Corá et al. 2005).

The experimental grove was planted in May 2001, and the evaluations were performed up to the fifth harvest, in 2008. Tree spacing was 6.0 m × 2.5 m (666 trees·ha^{-1}), and drip irrigation was installed in 2006. Dolomitic limestone was applied before installing the experiment (70% acid neutralizing capacity to increase soil base saturation to 70%), and it was reapplied whenever the soil base saturation reached 60%. The mean annual fertilization rates applied per tree were 140 g of Nitrogen, 60 g of P_2O_5 and 99 g of K_2O. Other standard practices for mandarin cultivation in Brazil were used (Mattos Junior et al. 2005), except for fruit thinning and pruning.

Ten Satsuma mandarin selections were studied: Clausellina, Okitsu, Unshu SRA-529, Saigon SRA-227, Panaché SRA-579, Salzara SRA-341, Miyagawa SRA-444, Kowano SRA-167, FCAV-59 and A2 60.0. Virus and viroid-free budwood were obtained from the screen house of the Citrus Experimental Station of Bebedouro (EECB) collection. All selections were grafted on nucellar seedlings of Swingle citrumelo, and most of them were originally introduced from the Agrumes Agricultural Research Station (SRA), in Corsica, France, and from the Instituto Valenciano de Investigaciones Agrarias (IVIA), in Valencia, Spain. FCAV-59 is a nucellar line selected by Prof. Dr. Luiz Carlos Donadio at the "Júlio de Mesquita Filho" São Paulo State University (FCAV/UNESP) in Jaboticabal, Brazil, and A2 60.0 was a local selection of Okitsu considered more productive than the mother tree (Cyrillo 2000)[4].

The following plant growth variables were annually assessed from 2006 to 2008: canopy height (CH), measured from the ground to the top of the tree; mean canopy diameter (CD), calculated as the average canopy width in parallel (Dl) and perpendicular (Dr) directions to the tree row; and the canopy volume (CV), calculated as follows: CV = (π/6) × CH × Dl × Dr (Cantuarias-Avilés et al. 2010). Mean fruit yield (FY) per tree in the 2004–2008 period was calculated as the average of the five initial harvests. For the same period, the alternate bearing index (ABI) was calculated by the expression:

$$ABI = [1/(n - 1)] \times \{[|a_2 - a_1|/(a_2 + a_1)] + [|a_3 - a_2|/(a_3 + a_2)] + \ldots + [|a_n - a_{n-1}|/(a_n + a_{n-1})]\}$$

where n is the total number of years, and a_1, a_2, ..., a_{n-1}, a_n = yield of the corresponding year (Pearce and Doberšek-Urbanc 1967). The percentage of cumulative yield until the

[4]Cyrillo, F. L. L. (2000). Avaliação fenotípica de seleções de tangerina "Satsuma" (Citrus unshiu Marcow.) nas condições climáticas da região de Jaboticabal. (Master's Dissertation). Jaboticabal: Faculdade de Ciências Agrárias e Veterinárias, Universidade Estadual Paulista.

second commercial harvest (2005) was used to estimate early bearing (Cantuarias-Avilés et al. 2010). Mean yield efficiency (YE) from 2006 to 2008 was calculated from the ratio between mean annual fruit yield (FY) ($kg.tree^{-1}$) and canopy volume (CV, $m^3 \cdot tree^{-1}$).

For fruit quality analyses, ten fruits per plot were sampled in April during 2006, 2007 and 2008, according to the visual maturation and softness. The following variables were annually assessed: fruit weight, diameter, and height; total soluble solids (TSS), measured with a refractometer (Palette PR-101, ATAGO, Tokyo, Japan); titratable acidity (TA), obtained by titration with sodium hydroxide (0.3125 N); and the maturity index (MI), calculated as TSS/TA. Juice yield (%) was determined by using an extractor designed for point-of-sale small lot juicing (Otto 1800, OIC, Limeira, São Paulo, Brazil).

The trial was set following a randomized block design, with ten treatments (Satsuma mandarin selections), three replicates and two trees in the plot. Results were submitted to the analysis of variance and means were grouped by the Scott-Knott test ($p \leq 0.05$). Data were submitted to an arcsine square root for normalization and to reduce heterogeneity of variance.

RESULTS AND DISCUSSION

Unshu, Miyagawa and A2 60.0 selections showed larger canopy volume (mean of 27.35 m^3) because of their higher plants, with wider diameters (Table 1). Saigon and Panaché also exhibited wider trees. When mean fruit yield was analyzed, two groups of selections were formed, classified by mean fruit yield (FY) in 2004–2008. Miyagawa, A2 60.0, Unshu, Kowano and Okitsu mandarins presented higher FY (mean of 31.3 $kg \cdot tree^{-1}$) than Saigon, Clausellina, Salzara, FCAV-59 and Panaché (mean of 14.2 $kg \cdot tree^{-1}$). In the 2006–2008 period, all the selections showed a similar mean yield efficiency between 2.88 and 5.39 kg fruits$\cdot m^{-3}$, except Panaché (0.48 kg fruits$\cdot m^{-3}$ canopy volume) (Table 1).

Both Miyagawa and A2 60.0 selections produced about 12% of the cumulative yield until the second commercial harvest (2005), being the earliest bearers (Table 1). On the other hand, the Unshu, Saigon, Panaché and FCAV-59 selections yielded very low crops in the same years, and Clausellina, Okitsu, Salzara and Kowano also presented intermediary, to low productions, of around 5.5% of total cumulative yield obtained in the first two crops. These performances could be attributed to the lack of irrigation that started to be applied only in 2006. Consequently, the Miyagawa and A2 60.0 selections presented lower alternate bearing in the evaluated period (ABI < 0.40), while the other selections had 0.55 < ABI < 0.70 (Table 1).

Fruit quality was annually assessed in April during the 2006–2008 period, considering the early ripening of most of the selections. Three fruit weight classes were determined: (i) Okitsu, Miyagawa and A2 60.0 selections with 215 g mean fruit weight; (ii) Clausellina, Unshu, →

Table 1. Canopy diameter (CD), height (CH) and volume (CV) in 2008 and mean fruit yield (FY), alternate bearing index (ABI), early bearing (EB) and average yield efficiency (YE) of ten Satsuma mandarin selections grafted on Swingle citrumelo from 2004 to 2008 (five initial harvests) in Bebedouro, northern São Paulo state, Brazil.

Satsuma mandarins	CD (m)	CH (m)	CV (m^3)	FY ($kg \cdot tree^{-1}$)	ABI	EB* (%)	YE** ($kg \cdot m^{-3}$)
Clausellina	2.74 b	2.38 b	9.57 b	18.7 b	0.62 a	6.38 b	5.39 a
Okitsu	3.09 b	2.93 b	15.08 b	26.4 a	0.55 a	7.28 b	4.51 a
Unshu SRA-529	4.31 a	3.55 a	35.18 a	29.4 a	0.62 a	0.05 c	3.11 a
Saigon SRA-227	3.58 a	2.71 b	18.73 b	19.9 b	0.67 a	0.15 c	3.88 a
Panaché SRA-579	3.59 a	2.73 b	19.37 b	3.5 b	0.66 a	0.00 c	0.48 b
Salzara SRA-341	3.47 b	3.00 b	19.28 b	18.1 b	0.70 a	4.76 b	4.07 a
Miyagawa SRA-444	3.78 a	2.89 b	22.48 a	41.2 a	0.38 b	13.3 a	5.23 a
Kowano SRA-167	3.35 b	2.83 b	16.86 b	27.1 a	0.56 a	4.17 b	4.28 a
FCAV-59	3.25 b	2.82 b	15.82 b	10.8 b	0.58 a	0.00 c	2.88 a
A2 60.0	3.63 a	3.23 a	24.41 a	32.4 a	0.40 b	10.3 a	4.27 a
CV (%)	11.47	8.86	30.86	34.65	13.61	35.94	24.49

Means followed by the same letter in the column are in the same group by the Scott-Knott test ($p \leq 0.05$). *Percentage of total accumulated fruit production corresponding to the first two harvests; **Mean of the 2006-2008 period.

Saigon, FCAV-59 and Kowano selections, with 185 g mean fruit weight; and (iii) Panaché and Salzara with the lightest fruits, weighing 133 and 159 g, respectively (Table 2). These results were directly correlated with fruit size variables, once the Okitsu, Miyagawa and A2 60.0 selections produced larger fruits (height > 7.7 and diameter > 8.15 cm), and a similar composition of the other two fruit size classes' selections (Table 2).

The selections with the highest juice percentage were Saigon, Panaché and Salzara (mean of 48.2%) (Table 2). Unshu, Miyagawa, FCAV-59, A2 60.0 and Kowano formed the second group, with an average of 40.0% juice content. Clausellina and Okitsu had the lowest juice percentage, of approximately 30%. Regarding the TSS content, two groups of selections were observed: (i) Clausellina, Okitsu, Saigon, Panaché, Salzara, Kowano and FCAV-59, with 8.42 < TSS < 8.82 °Brix; and (ii) Unshu, Miyagawa and A2 60.0, with 7.93 < TSS < 8.23 °Brix (Table 2).

In terms of titratable acidity (TA), the selections were classified into three groups: (i) Panaché (TA = 0.88%); (ii) Unshu, Saigon, Salzara, Kowano and FCAV-59, with 0.70 < TA < 0.76%; and (iii) Okitsu, Clausellina, Miyagawa and A2 60.0, with TA < 0.61%). Consequently, Panaché is probably a later variety, while Okitsu and Clausellina are known as early-season varieties. This observation is confirmed by the maturity index (MI) of the selections in April, when Panaché and Unshu presented the lowest values (10.68 and 11.41, respectively), while Clausellina, Okitsu, Miyagawa and A2 60.0 showed the highest MI (mean of 14.57), with the remaining selections being intermediate in maturation (Table 2).

The results presented herein on the horticultural performance of ten Satsuma mandarin selections grafted on Swingle citrumelo confirm the potential use of these groups of mandarin for cultivation in subtropical conditions. Some selections were identified as more productive and presented fruits that better fit the objective of early-season harvest and highly valuable fruits for the Brazilian domestic market. Early harvest from January to April is very important due to the low supply of traditional Ponkan and Murcott mandarins for fresh consumption during these months. Even though Cravo and Willowleaf mandarins are also early ones and available during that period, their fruits are extremely seedy and less appreciated by the internal market.

Average fruit yield of the most productive selections identified in this study (Miyagawa, A2 60.0, Unshu, Kowano and Okitsu) was 31.3 kg·tree^{-1}, which gives estimate productivity of 20.84 t·ha^{-1}, considering the evaluated tree density (666 trees·ha^{-1}). This value is lower than the mean recorded mandarin yield in São Paulo state in 2016 (33.1 t·ha^{-1}), yet it could be considered as a promising production for early mandarin selections, when compared to the highly productive standards of Ponkan mandarin and Murcott tangor (Pio et al. 2005). In the first five to six harvests, Tazima et al. (2013; 2014) and Cantuarias-Avilés →

Table 2. Mean fruit weight (FW), diameter (FD) and height (FH), juice yield (JY), total soluble solids concentration (TSS), titratable acidity (TA) and maturity index (SS/TA) of ten Satsuma mandarin selections grafted on Swingle citrumelo from 2006 to 2008* (third to fifth harvests) in Bebedouro, northern São Paulo state, Brazil.

Satsuma mandarins	FW (g)	FD (cm)	FH (cm)	JY (%)	TSS (°Brix)	TA (%)	SS/TA
Clausellina	183 b	7.65 b	7.31 b	32.2 c	8.48 a	0.57 c	14.9 a
Okitsu	225 a	8.30 a	8.09 a	31.5 c	8.49 a	0.61 c	14.0 a
Unshu SRA-529	185 b	7.76 b	7.25 b	40.9 b	8.23 b	0.76 b	11.4 c
Saigon SRA-227	192 b	7.90 b	7.23 b	50.2 a	8.65 a	0.71 b	12.4 b
Panaché SRA-579	133 c	6.65 d	6.03 c	46.9 a	8.68 a	0.88 a	10.6 c
Salzara SRA-341	158 c	7.30 c	6.73 b	47.5 a	8.42 a	0.71 b	12.3 b
Miyagawa SRA-444	215 a	8.31 a	7.96 a	41.0 b	7.93 b	0.56 c	14.3 a
Kowano SRA-167	177 b	7.71 b	6.99 b	44.5 b	8.82 a	0.70 b	13.1 b
FCAV-59	185 b	7.85 b	7.23 b	42.5 b	8.61 a	0.72 b	12.3 b
A2 60.0	205 a	8.16 a	7.78 a	41.1 b	7.98 b	0.54 c	15.1 a
CV (%)	8.51	3.91	4.97	9.24	2.98	7.01	5.36

Means followed by the same letter in the column are similar according to the Scott-Knott test (p ≤ 0.05). *Fruits harvested in April in every evaluated year.

et al. (2010) reported contradictory results for average fruit yield of Okitsu grafted on Swingle citrumelo, ranging from 129 to 154 kg·tree^{-1}. This variation in yield could be attributed to differences in the orchard management and edaphoclimatic conditions. According to these authors, Swingle citrumelo induced a high to intermediate fruit yield compared to other rootstocks, such as Rangpur lime, Cleopatra mandarin (*C. reshni* Hort. ex. Tanaka) and the citranges (*C. sinensis* × *P. trifoliata*).

Tree size is a major issue for mandarin cultivation, with smaller trees being preferred, as they facilitate the cultural practices, notably the manual harvesting of soft fruits. We observed that canopy volume of 7-year-old Okitsu mandarin trees was 15 m^3, which is similar to that described for this selection grafted on Swingle citrumelo in São Paulo and Paraná states, of 12 and 17 m^3, respectively (Cantuarias-Avilés et al. 2010; Tazima et al. 2014). Some selections, such as Unshu (35 m^3), presented higher canopy volume compared to the overall results reported for Okitsu. The use of dwarfing rootstocks such as Flying Dragon trifoliate orange (*P. trifoliata* var. *monstrosa*) is an option for high-density Satsuma mandarins orchards, resulting in smaller trees which are less productive than those grafted onto Swingle citrumelo (Cantuarias-Avilés et al. 2010; Abedi-Gheshlaghi et al. 2012; Andersen and Brodbeck 2015).

In general, fruits of all the evaluated selections of Satsuma mandarin had similar physic and chemical characteristics than those reported in previous studies carried out in Brazil (Donadio et al. 1998; Silva et al. 2009; Cantuarias-Avilés et al. 2010; Tazima et al. 2014). The fruits were usually larger and had higher maturity index than the the minimum standard values established by the UNECE (2016), but the Okitsu and Clausellina selections had juice contents under the minimum of 33% necessary for exportation. Distinctly, the juice content of Okitsu and Clausellina grafted on Rangpur lime (*C. limonia* Osbeck) was informed to be around 45% (Donadio et al. 1998).

The mandarin fruit quality standards for domestic market established by the São Paulo Company of Warehouses and General Storage define a minimum juice content of 35% to 40%, and a minimal TSS content and maturity index of 9.0 °Brix and 9.5, respectively (CEAGESP 2011). All the evaluated selections in this study reached the minimum juice content and maturity index, except for Okitsu and Clausellina. However, all selections had low TSS contents, and this characteristic seems inherent to the Satsuma mandarins, even when cultivated in other regions (Duarte et al. 2006; Tietel et al. 2010). Silva et al. (2009) observed higher TSS in fruits of the same Satsuma selections grafted on Rangpur lime in São Paulo. In this study, Okitsu grafted on Swingle citrumelo produced fruit with higher TSS than that reported by Cantuarias-Avilés et al. (2010) in the same experimental site (7.8 °Brix), but lower than the results presented by Tazima et al. (2014) in Paraná, under milder climatic conditions (9,73 °Brix).

Miyagawa, A2 60.0, Clausellina and Okitsu had higher mean maturity index as compared to the other selections. Unshu and Kowano presented a lower maturity index than Okitsu, despite their similar fruit yield, indicating an undesirable later maturation that overlaps Ponkan mandarin harvesting season in Brazil. These results confirm the early-bearing habit of Okitsu (Saunt 2000; Hodgson 1967) and Miyagawa (Hodgson 1967; Silva et al. 2009) mandarins, and the late maturation of Unshu, according to Hodgson (1967).

A2 60.0 is a putative and more productive clone of Okitsu, but in this study, it did not show this characteristic. The Okitsu selection is supposedly a chance-seedling of the Miyagawa mandarin obtained in Japan (Oliveira et al. 2005), which in turn presented fully mature fruits in February and March in São Paulo state (Silva et al. 2009). The results obtained in this study corroborate this common origin, since both the A2 60.0 and Miyagawa selections had similar fruit yield and size, with higher juice content and lower than Okitsu. Both selections also proved to be early-bearers. Finally, it is worth to mention that all the evaluated selections of Satsuma mandarin yield seedless fruits and no visual symptoms of Alternaria brown spot neither graft incompatibility were observed throughout the evaluation period.

CONCLUSION

The Okitsu, Miyagawa and A2 60.0 selections of Satsuma mandarin were selected for cultivation on Swingle citrumelo rootstock in regions with similar subtropical conditions because of their high production of fruits with large size and early maturation.

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AUTHORS' CONTRIBUTION

Conceptualization: Stuchi, E; Methodology: Stuchi, E, Silva, S, Girardi, E. and Cantuarias-Avilés, T; Investigation: Stuchi, E, Silva, S, Parolin, L.G., Reiff, E, Sempionato, O; Writing – Original Draft: Stuchi, E., Girardi, E., Cantuarias-Avilés and Silva, S; Writing – Review and Editing: Stuchi, E, Silva, S, Girardi, E. Cantuarias-Avilés; Funding Acquisition: Stuchi, E. and Sempionato, O.; Resources: Sempionato, O. and Stuchi, E.; Supervision: Stuchi, E.

ORCID IDs

E. S. Stuchi
https://orcid.org/0000-0001-6194-0117
Eduardo Augusto Girardi
https://orcid.org/0000-0003-4839-5227
S. R. Silva
https://orcid.org/0000-0002-8471-956X
T. Cantuarias-Avilés
https://orcid.org/0000-0002-0195-0185
L. G. Parolin
https://orcid.org/0000-0002-0922-2254
E. T. Reiff
https://orcid.org/0000-0001-8019-9467
O. R. Sempionato
https://orcid.org/0000-0003-1187-1517

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