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Evaluation of the biometric and qualitative characteristics of 'Okitsu' Satsuma mandarins grown on different rootstocks

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Abstract

The present work evaluated the qualitative and biometric characteristics of the 'Okitsu' Satsuma mandarin grafted on different rootstocks. The following rootstocks were evaluated: 'Carrizo' citrange, 'Swingle' citrumelo, and trifoliate orange. The quality characteristics evaluated were longitudinal and transversal fruit diameter, average fruit mass, juice content, soluble solids content, titratable acidity, ratio, and ascorbic acid content. Fruit peel essential oil yield and composition were also evaluated. The characteristics of longitudinal diameter, soluble solids content, juice content, ascorbic acid content, and limonene and p-cymene contents were not influenced by the rootstock. Transversal diameter, average fruit mass, titratable acidity, essential oil yield, and linalool content were influenced by the rootstock used. The 'Citrange' rootstock caused an increase in average fruit mass and linalool content, whereas fruits from plants grafted on trifoliate orange rootstock have had lower average fruit mass and higher titratable acidity and essential oil content.

Palavras-chave: *Citrus unshiu* Marc; essential oil; fruit quality; terpenes.

Resumo

Avaliação dos parâmetros biométricos e de qualidade de mandarinas Satsuma 'Okitsu' cultivadas sobre diferentes porta-enxertos

O presente trabalho avaliou as características qualitativas e biométricas da tangerina 'Okitsu' Satsuma enxertada em diferentes porta-enxertos. Foram avaliados porta-enxertos citrangeiro 'Carrizo', citrumeleiro 'Swingle' e trifoliateiro. Os parâmetros de qualidade avaliados foram diâmetro longitudinal e transversal do fruto, massa média do fruto, teor de suco, teor de sólidos solúveis, acidez titulável, proporção e teor de ácido ascórbico. O rendimento e a composição do óleo essencial de casca de fruta também foram avaliados. Os parâmetros de diâmetro longitudinal, teor de sólidos solúveis, teor de suco, teor de ácido ascórbico e teores de limoneno e p-cimeno não foram influenciados pelo porta-enxerto. Diâmetro transversal, massa média do fruto, acidez titulável, rendimento de óleo essencial e teor de linalol foram influenciados pelo porta-enxerto utilizado. O porta-enxerto citrangeiro causou aumento na massa média do fruto e no teor de linalol, enquanto os frutos de plantas enxertadas no porta-enxerto trifoliateiro apresentaram menor massa média de frutos, maior acidez titulável e teor de óleo essencial.

Keywords: *Citrus unshiu* Marc; óleo essencial; qualidade de frutos; terpenos

Resumen

Evaluación de parámetros biométricos y de calidad de mandarinas Satsuma 'Okitsu' cultivadas en diferentes portainjertos

El presente trabajo evaluó las características cualitativas y biométricas de la mandarina 'Okitsu' Satsuma injertada en diferentes portainjertos. Se evaluaron portainjertos de citrange 'Carrizo', citrumelo 'Swingle' y naranjo trifoliado. Los parámetros de calidad evaluados fueron diámetro de fruto longitudinal y transversal, masa promedio de fruto, contenido de jugo, contenido de sólidos solubles, acidez titulable, proporción y contenido de ácido ascórbico. También se evaluó el rendimiento y la composición del aceite esencial de la cáscara de fruta. Los parámetros de diámetro longitudinal, contenido de sólidos solubles, contenido de jugo, contenido de ácido ascórbico y contenido de limoneno y p-cimeno no fueron influenciados por el portainjerto. El diámetro transversal, la masa promedio del fruto, la acidez titulable, el rendimiento de aceite esencial y el contenido de linalol fueron influenciados por el portainjerto utilizado. El portainjerto citrange provocó un aumento en la masa media del fruto y en el contenido de linalol, mientras que los frutos de plantas injertadas sobre portainjertos de naranjo trifoliado tuvieron menor masa media de frutos, mayor acidez titulable y contenido de aceite esencial.

Palabras clave: *Citrus unshiu* Marc; aceite esencial; calidad de frutos; terpenos.

Introduction

Cultivation of *Citrus* fruits has great importance in the Brazilian agricultural sector, encompassing several Citrus varieties that are marketed throughout the year both domestically and abroad. *Citrus* juice highlights itself as the main export product of *Citrus* industry; however, *Citrus* fruit peel and bagasse are also widely used as feedstocks in food, chemical, and cosmetic industries, and in animal feed (BRON; JACOMINO, 2007).

The mandarin has the highest degree of climate adaptation among the *Citrus*, having resistance to both high and low temperatures. Some regions of Rio Grande do Sul state have specific microclimates that favor the production of this fruit with high quality. These regions have a wide thermal amplitude, which renders to fruits a sharp coloring and a good balance between soluble solids and acidity (SS/TA ratio) (MAPA, 2011). The 'Okitsu' satsuma (C. *unshiu* Marc.) is a mandarin scion characterized by having tolerance to low temperatures and *citrus* canker (*Xanthomonas citri* subsp. citri).

The use of rootstocks is a mandatory procedure in *Citrus* management; rootstock may influence more than twenty horticultural and disease-related characteristics of the scion cultivar and, consequently, its fruits. A suitable rootstock provides resistance, tolerance, or susceptibility to diseases and stress from edaphoclimatic factors to the scion cultivar, besides being also capable of influencing fruit biometric and quality characteristics (SCHAFER; BASTIANEL; DORNELLES, 2001). Thus, the diversification of the use of different rootstocks in *Citrus* orchards, as well as the introduction of new genotypes is essential to avoid the development of plant vulnerabilities to the attack of phytopathogens (BASTOS *et al*., 2014).

The 'Swingle' citrumelo (*Citrus paradisi* × *Poncirus trifoliata*) is a hybrid rootstock, being the second most used in citriculture worldwide until 2010 (DANTAS, 2009; BOWMAN; JOUBERT, 2020). 'Swingle' citrumelo is tolerant to the *Citrus* tristeza virus (CTV), *Phytophthora gummosis*, exocortis, xyloporosis, *Citrus* decline, *Citrus* sudden death (CSD), nematodes, cold, and has a moderate tolerance to drought (BASTOS, 2014). Scions grafted on 'Swingle citrumelo' rootstock have good productivity both in clayey and sandy soils, with moderate tolerance to drought and frost, but poor performance in poorly drained or alkaline (pH >7.0) soils (POMPEU JUNIOR, 2009).

The trifoliate orange [*Poncirus trifoliata* (L.) Raf.] is the main *Citrus* rootstock used in Rio Grande do Sul State and is compatible with most *Citrus* species (SULZBACH et al., 2016). It has a high tolerance to cold, with resistance to CTV, CSD, *Phytophthora gummosis*, and the nematode *Tylenchulus semipenetrans*, being well adapted to the climatic conditions of South Brazil, especially in Rio Grande do Sul state (SCHAFER; BASTIANEL; DORNELLES, 2001). One particularity of trifoliate orange is that this rootstock has a 'dwarfing' effect on the scion, rendering the plant smaller than when the scion is grafted on other rootstocks. Smaller canopies facilitate harvesting and management and tend to produce fruits with higher soluble solids (sugar) content and titratable acidity, which enhances the overall fruit flavor (GONZATTO *et al*., 2018).

The ‘Carrizo’ citrange [*Poncirus trifoliata* (L.) Raf. × *Citrus sinensis* (L.) Osbeck] is also a hybrid rootstock. It is large, which induces good fruit quality and high productivity, with an intermediate starting production. This rootstock has medium tolerance to gummosis, but it is susceptible to Citrus decline and the nematode Tylenchulus semipenetrans. In relation to climatic conditions, the ‘Carrizo’ citrange has a low tolerance to drought and waterlogging (BASTOS, 2014).

Another product of Citrus processing is Citrus fruit peel essential oil. The essential oil is largely used in the production of perfumes, cosmetics, chemicals, and pharmaceuticals, besides being also marketed in raw form, being a source of terpenes, such as limonene, which is an important compound of *Citrus* essential oils and whose content may range between 30 and 97 wt.%, depending on the species (MEHL *et al*., 2014; SILVESTRE *et al*., 2016).

The essential oil obtained from *Citrus* fruit peel is considered a secondary product or by-product of *Citrus* industry. Since Brazil is the largest producer of orange juice, the bagasse and peel need to receive adequate disposal to avoid excessive waste generation. Considering that, despite the much smaller market share than juice, the peel essential oil of Citrus is widely used in industry for several purposes that range from the production of chemicals to pharmaceuticals and cosmetics (PAULETTI; SILVESTRE, 2018).

In general, Citrus peel essential oil is composed of monoterpenes, such as limonene, γ-terpinene, and sabinene, whereas Citrus leaf essential oil is composed mainly of oxygenated monoterpenes (linalool, linalyl acetate, methyl N-methylanthranilate) and monoterpenes (sabinene, myrcene, α-thujene) (PAULETTI; SILVESTRE, 2018).

Thus, this work aimed to evaluate the effect of different rootstocks on biometric and quality characteristics, also evaluating peel essential oil composition and yield, of ‘Okitsu’ Satsuma mandarins cultivated in ‘Vale do Caí’ region, South Brazil.

Material and methods

The experimental orchard was located in UCS Vale do Caí Campus, in the town of São Sebastião do Caí, at the geographical coordinates of 29°37’03.4” S and 51°20’45.3” W, and an average altitude of 18 m above sea level. This region is characterized as Cfa (subtropical humid with hot summer) climate (ALVARES *et al*., 2013). Orchard soil kind was arenic acrisol (SANTOS *et al*., 2018). The tangerine plants were four years old, all ‘Okitsu’ Satsuma scion variety, grafted on trifoliate orange, ‘Swingle’ citrumelo, and ‘Carrizo’ citrange rootstocks. Orchard management was carried out following the procedures described by Efrom and Souza (2018). All plants were conducted under the same type of management.

The experiment was carried out in 2018/2019 harvest. In this period, the accumulated rainfall in the region was 1550.3 mm, the average temperature was 19.5 °C, and the maximum temperature range was 3.0-38.3 °C (INMET, 2020). According to Efron and Souza (2018) and Böettcher, Gonzatto, and Petry (2018), these climatic conditions are suitable for the growth and fruiting of *Citrus* plants.

The fruits were collected on March 13, 2019. Fifty fruits were collected from five plants (ten fruits from each plant) with the same rootstock, making up 15 plants used in the experiment. Thirty fruits were used in biometric evaluations and 20 fruits were grouped randomly in four sub-samples of five fruits to determine the quality characteristics.

The following biometric and quality characteristics of the mandarins were evaluated: transversal and longitudinal diameters, average fruit mass, soluble solids content, titratable acidity, juice content, and ascorbic acid content. Transversal and longitudinal diameters were measured using a digital caliper, average juice mass was determined by weighing in a digital balance, and juice content was determined following the procedures described by Zanardi, Silvestre, and Pauletti (2021).

Soluble solids content was determined following the method 315/IV of Instituto Adolfo Lutz (IAL, 2008). The titratable acidity was determined following the method 312/IV (IAL, 2008). The SS/TA ratio was calculated as the quotient between the soluble solids content and the titratable acidity (ratio = SS/TA). The ascorbic acid content was determined following the method 364/IV (IAL, 2008).

The essential oil was extracted by hydrodistillation, using the peel of the fruits pulped in juice extraction. A Clevenger apparatus and a 5 L round-bottom flask were used. Two liters of distilled water were used in the extraction; the process was carried out for 4 h (ANVISA, 2010). The volume of obtained essential oil was measured using a graduated scale in the Clevenger apparatus (measurement range of 0.0-3.0 mL and resolution of 0.05 mL), being posteriorly collected, and stored in amber glass flasks; a small sample (0.5 mL) was immediately sent to chromatographic analysis. Essential oil yield was calculated using equation 1.

$$Y = 100 \times \frac{V}{M} \qquad (1)$$

Being 'Y' the essential oil yield (% v/w), 'V' the volume of essential oil collected at the end of the extraction (mL), and 'M' the mass of fruit material used in the extraction (g).

The chromatographic analyses were carried out based on the procedures described by Vicenço *et al.* (2020). The constituents of the essential oils were identified by comparison of their mass spectra with the ones of Wiley spectral library (GC/MS) and by comparing the linear retention index (LRI) from literature data (ADAMS, 2017). The LRI values were calculated using Van den Dool and Kratz equation and retention times of a C8-C30 alkane standard, under the same chromatographic conditions.

The study was carried out in a completely randomized design, with three treatments (each rootstock), and each experimental parcel was composed by a plant. Out of the 50 fruits collected in each treatment, 30 fruits were randomly grouped in six replicates with five fruits each for the determination of biometric characteristics. For the determination of quality characteristics, the other 20 fruits were grouped in four replicates of five fruits each; the same design was used in essential oil extraction and its chemical characterization. The obtained results underwent Levene's test (homogeneity of variances) and Shapiro-Wilk (normality) test, followed by analysis of variance (ANOVA) at 5 % error probability. The means were compared by Tukey's multiple range test at 5 % error probability (p = 0.05).

Results and discussion

Effect of rootstocks on fruit biometric and qualitative characteristics

The results of longitudinal and transversal diameter and average fruit mass referring to each rootstock are presented in Table 1.

Table 1 – Biometric and fruit quality characteristics of 'Okitsu' satsuma mandarins grafted on 'Carrizo' citrange, 'Swingle' citrumelo, and trifoliate orange rootstocks.

Characteristic	Rootstock			CV[1] (%)
	'Carrizo' citrange	'Swingle citrumelo'	Trifoliate orange	
Longitudinal diameter (mm)	59.64 a	59.14 a	60.50 a	1.77
Transversal diameter (mm)	75.36 a	73.90 a	71.28 b	9.55
Average fruit mass (g)	182 a	168 ab	153 b	5.64
Soluble solids (°Brix)	9.22 a	9.15 a	9.07 a	2.08
Titratable acidity[2] (% w/v)	0.70 b	0.69 b	0.88 a	9.55
Juice content (% v/w)	46.41 a	45.13 a	49.55 a	16.75
SS/TA ratio	13.18 a	13.26 a	10.31 b	6.27
Ascorbic acid ($mg \cdot 100\ mL^{-1}$)	26.80 a	23.70 a	23.30 a	7.72

Means in column followed by the same letter do not differ statistically by Tukey's multiple range test at 5 % error probability (p = 0.05). [1] – Coefficient of variation; [2] – As mass-equivalent of citric acid. Source: authors (2021).

According to Table 1, the longitudinal diameter of the fruits was not influenced by the rootstock. Referring to the transversal diameter, the fruits from the plants grafted on trifoliate orange have had smaller transverse diameters, the other two rootstocks have not differed. Tazima *et al.* (2013), who evaluated the biometric characteristics of 'Okitsu' Satsuma mandarins grown on nine different rootstocks in Paraná state (South Brazil), observed that rootstock kind has not influenced fruit longitudinal diameter, but influenced the transversal diameter. The same authors reported that results of fruit transversal diameter from the scion grafted on

‘Carrizo’ citrange and ‘Swingle’ citrumelo rootstock have not differed statistically, whereas the ones grafted on trifoliate orange presented a statistically smaller transversal diameter, being the same behavior observed in the present work.

Nuñez, Mourão Filho, and Stuchi (2007), evaluating biometric characteristics of ‘Fremont’ tangerine (*C. clementina* Hort. ex Tan. × *C. reticulata* Blanco) grafted on Rangpur (*C. limonia* Osbeck), ‘Swingle’ citrumelo (*P. trifoliata* Raf. × *C. paradisi* Macf.), ‘Cleopatra’ mandarin (*Citrus reshni* Hort. ex Tan.), and ‘Orlando’ tangelo (*C. reticulata* Blanco × *C. paradisi* Macf.) rootstocks, reported that the biometric characteristics were not influenced significantly by the rootstock. Rodrigues *et al*. (2019), evaluating the performance of ‘Valencia’ sweet oranges grown on nine different rootstocks in the state of Acre, North Brazil, also observed that fruit length and diameter and peel thickness were not influenced by the rootstock. Moreover, the same authors also commented that the degree and kind of interaction between rootstock and scion are highly dependent on the combination scion/rootstock.

Referring to average fruit mass, the fruits whose scion was grafted on ‘Carrizo’ citrange presented a higher mass (182 g) than the ones produced by plants grafted on trifoliate orange (153 g); the mass of the fruits from plants grafted on ‘Swingle’ citrumelo have not differed from the other two rootstocks (168 g). Tazima *et al*. (2013) reported similar behavior, however, fruits from the plants grafted on trifoliate orange have had a significantly smaller fruit mass than the ‘Carrizo’ citrange and ‘Swingle’ citrumelo rootstocks, which have not differed between themselves. Santos (2016) reported an optimal average fruit mass of 160 g for ‘Ponkan’ tangerines. Rodrigues *et al.* (2019) reported an average fruit mass of 169.85 g for ‘Valencia’ sweet oranges grafted on nine different rootstocks; according to the results, the rootstock kind influenced average fruit mass.

Domingues *et al.* (2003) commented that the optimal mass for commercialization is about 150 g for tangerines. On the other hand, Schwarz (2011) cited that fruits with an average mass of 170-220 g are considered optimum for commercialization. Considering that the average fruit mass ranged between 153 g and 182 g, the three rootstocks may be considered adequate to be used when considering fruit mass.

Nuñez, Mourão Filho, and Stuchi (2007), who studied the effect of rangpur, ‘Swingle’ citrumelo, ‘Cleopatra’ mandarin, and ‘Orlando’ tangelo rootstocks on ‘Fremont’ tangerines, reported that average fruit mass was not affected by the rootstock. However, the opposite behavior was observed in the present work, in which average fruit mass was influenced by the rootstock. Cerri Neto *et al*. (2016), who evaluated the physical-chemical properties of seven lime orange (*Citrus sinensis* L. Osbeck.) genotypes grafted on the Rangpur rootstock, also reported no rootstock influence on fruit mass. However, the ‘dwarfing’ effect of trifoliate orange rootstock on the scion cultivars, which is widely reported in the literature, may have been responsible for the smaller fruit mass (EFROM; SOUZA, 2018).

For the qualitative factors, soluble solids, juice, and ascorbic acid contents were not influenced by the rootstocks since there was no statistical difference in the results for these characteristics. On the other hand, titratable acidity and ratio values were influenced by the rootstock. The data on qualitative characteristics of the tangerines are presented in Table 1.

Fruits from the scions grafted on trifoliate orange rootstock have had higher titratable acidity (0.88 % w/v) than the other rootstocks (0.70 % and 0.69 % w/v for ‘Carrizo’ citrange and ‘Swingle’ citrumelo, respectively); the SS/TA ratio value of the fruits whose rootstock was trifoliate was smaller (10.31) than the other two (13.18 and 13.26). Tazima *et al*. (2013), on the other hand, reported that neither of these rootstocks influenced the titratable acidity of ‘Okitsu’ satsuma mandarins (0.68-0.69 % w/v); however, other rootstocks increased the fruits titratable acidity.

Gomes *et al.* (2018) evaluating the quality characteristics of ‘Ponkan’ tangerines grafted on Rangpur, Cleopatra mandarin, and ‘Swingle’ citrumelo rootstocks, reported that the rootstocks have not influenced soluble solids content and ratio values. Nuñez, Mourão Filho, and Stuchi (2007) also commented that no quality characteristics were affected by rootstock type. Cerri Neto *et al*. (2016) reported no effect of the rootstock on the soluble solids content of the fruits. On the other hand, Tazima *et al*. (2013) observed that soluble solids content and ratio were influenced by the rootstock; the ‘Swingle’ citrumelo presented a smaller ratio value and soluble solids content than ‘Carrizo’ citrange and trifoliate orange, which have not differed between themselves.

Titratable acidity, which ranged between 0.69 % and 0.88 % w/v, was higher in the fruits whose scions were grafted on trifoliate orange rootstock (0.88 % w/v), it differed statistically from the other two rootstocks, which presented nearly the same value of titratable acidity (0.69 % w/v for ‘Swingle citrumelo’ and 0.70 % w/v for ‘Carrizo’ citrange, respectively). Gomes *et al*. (2018) reported titratable acidity of 0.72 % w/v for ‘Ponkan’ tangerines grafted on ‘Swingle’ citrumelo rootstock. Tazima *et al*. (2013) reported titratable acidity values in the range of 0.68 – 0.74 % w/v for ‘Okitsu’ satsuma mandarins grafted on different rootstocks.

According to the literature, scions grafted on the trifoliate orange rootstock tend to produce fruits with higher titratable acidity (CHITARRA; CHITARRA, 2005; EFROM; SOUZA, 2018). However, this behavior was not observed in the work of Tazima *et al*. (2013), in which fruits from scions grafted on the three rootstocks studied in the present work have not differed statistically (0.68-0.69 % w/v). The authors observed that scion cultivars grafted on ‘Rangpur’ lime, ‘Cleopatra’ mandarin, ‘C-13’ citrange, and ‘Volkamer’ lemon rootstocks produced fruits whose titratable acidity was statistically higher than the results observed in this work (0.71 – 0.74 % w/v).

Referring to juice content, there was no statistical difference among the rootstocks. Tazima *et al.* (2013) observed that, although this variable was influenced by rootstock type, the rootstocks ‘Carrizo’ citrange, ‘Swingle’ citrumelo, and trifoliate orange performed similarly (46.5-47.4 % v/w), not differing statistically; the same behavior was observed in the present work. Rodrigues *et al.* (2019), also observed that juice content was influenced by the rootstock, ranging between 39.1 % and 64.9 % v/w.

There was no rootstock influence on the ascorbic acid content of the fruits; it ranged between 23.3 mg·100 g^{-1} and 26.8 mg·100 g^{-1}. Zhu *et al*. (2020) also reported that rootstocks ‘Carrizo’ citrange, ‘Swingle’ citrumelo, and trifoliate orange have not influenced the ascorbic acid content of the fruits. However, Khalifa and Hamdy (2015), studying the influence of ‘Volkamerian’ lemon and sour orange rootstocks on the quality of ‘Balady’ and ‘Fremont’ mandarins, observed that the rootstock has influenced the mandarins’ ascorbic acid content. Fruits from scions grafted on sour orange rootstock have had a statistically higher ascorbic acid content (41 mg·100 g^{-1}) than those grafted on ‘Volkamerian’ lemon rootstock (34 mg·100 g^{-1}). Singh, Singh, and Mirza (2019) commented that few rootstocks may influence the ascorbic acid content of the fruits since this characteristic may be also highly dependent on environmental factors and the stress level of the plant.

Effect of rootstocks on essential oil yield and composition

Essential oil yield ranged between 0.024 % and 0.044 % v/w, and it was influenced by the rootstock type. Palazzolo, Laudicina, and Germanà (2013) reported that the customary range of peel essential oil yield for *Citrus* fruits ranges from 0.5 % to 5.0 % v/w. Luro *et al*. (2020), evaluating peel and leaf essential oil of several *Citrus* species, and an average essential yield of 0.48±0.24 % v/w for mandarins. However, it is important to highlight that these authors considered only the peel mass in the calculation of essential oil yield, and not total fruit mass as carried out in this study, this is the reason for the much low yield observed in the present work.

Fruits whose scions were grafted on trifoliate orange rootstock have had the highest yield (0.044 % v/w), whereas the ones whose scions were grafted on ‘Carrizo’ citrange have had the lowest yield (0.024 % v/w). Fruits whose scions were grafted on ‘Swingle’ citrumelo rootstock have not differed from any of the other two rootstocks, with an intermediate yield (0.035 % v/w).

According to the chromatographic analysis, the major compounds identified were limonene, p-cymene, and linalool. Relative to rootstock influence, only linalool content was influenced by rootstock kind; limonene and p-cymene contents have not presented statistical differences among treatments. The results of essential oil yield and major compound contents are presented in Table 2.

Table II – Peel essential oil yield and content of the major compounds of ‘Okitsu’ satsuma mandarins grafted on ‘Carrizo’ citrange, ‘Swingle’ citrumelo, and trifoliate orange rootstocks..

Rootstock	Content (wt.%)			Yield
	p-cymene	limonene	linalool	(% v/w)[1]
‘Carrizo’ citrange	3.06 a	74.69 a	6.21 a	0.024 b
‘Swingle’ citrumelo	3.13 a	89.55 a	1.72 b	0.035 ab
Trifoliate orange	2.95 a	75.83 a	3.01 ab	0.044 a
Coefficient of variation (%)	20.05	13.90	44.91	19.01

Means in column followed by the same letter do not differ statistically by Tukey’s multiple range test at 5 % error probability (p = 0.05). [1] – Yield relative to total fruit mass. Source: authors (2021).

Referring to the major compounds of the essential oils, linalool content was higher in the fruits from the plants grafted on ‘Carrizo’ citrange rootstock (6.21 wt.%), and lowest in those grafted on ‘Swingle’ citrumelo (1.72 wt.%). On the other hand, trifoliate orange presented 3.01 wt.%, not differing statistically from the other treatments.

Linalool is a compound with acknowledged antimicrobial and insecticidal properties; industry uses linalool as a component in several kinds of products and formulations, from perfumery to cosmetics, chemicals, and food industry. Essential oils with higher linalool contents may be of interest to industry mainly due to stronger biological activity and easier purification (VICENÇO *et al*., 2021). In this sense, the essential oil of the mandarins from the scions grafted on ‘Carrizo’ citrange rootstock had a more interesting composition than other rootstocks.

Tao *et al*. (2008), evaluating the chemical composition of ‘Okitsu’ satsuma mandarin peel essential oil obtained by hydrodistillation, reported limonene as the major compound (67.44 wt.%), followed by myrcene (7.45 wt.%), and α-pinene (2.45 wt.%). Cano and Bermejo (2011) reported limonene as the major compound (91.04-92.16 wt.%) of the peel essential oil from ‘Owari’ Satsuma mandarins (*C. unshiu*) grafted on both ‘Cleopatra’ and ‘Troyer’ rootstocks. Song *et al.* (2006), studying the essential oil of an ‘Okitsu’ satsuma hybrid (*C. unshiu* Marc. × *C. sinensis* Osbeck × *C. reticulata* Blanco – Japanese/Korean Shiranui), reported limonene as the major compound (86.36-91.82 wt.%), followed by myrcene (2.41-2.55 wt.%). The detailed chemical composition of fruit peel essential oil relative to the three rootstocks is presented in Table 3.

Table III - Chemical composition of the peel essential oils of ‘Okitsu’ satsuma mandarins grafted on ‘Carrizo’ citrange, ‘Swingle’ citrumelo, and trifoliate orange rootstocks.

Compound	Calc. LRI[1]	Lit. LRI[2]	Content (wt.%)		
			‘Carrizo’ citrange	‘Swingle’ citrumelo	Trifoliate orange
α-pinene	929	932	-	0.42	0.22
camphene	945	946	-	0.22	-
1-octen-3-ol	974	974	0.63	0.21	-
myrcene	990	988	0.56	1.18	0.85
octanal	995	998	0.82	0.24	0.39
limonene	1026	1024	74.69	90.02	85.83
p-cymene	1088	1089	3.06	3.01	3.23
linalool	1092	1095	6.21	1.47	3.01
nonanal	1104	1100	0.22	-	0.14
verbenol	1141	1140	0.25	-	-
terpinen-4-ol	1173	1174	0.73	0.23	0.41
cis-pinocarveol	1180	1182	0.31	0.11	-
α-terpineol	1189	1186	2.14	0.47	0.77
myrtenol	1195	1194	0.19	-	-

decanal	1203	1201	0.27	-	0.17
trans-carveol	1218	1215	0.42	0.15	-
cis-carveol	1230	1226	0.50	0.19	0.36
cuminal	1237	1238	0.80	0.21	-
carvone	1241	1239	0.66	0.25	0.51
geraniol	1250	1249	0.25	-	-
geranial	1260	1264	0.16	-	0.12
perillaldehyde	1268	1269	0.54	-	0.3
geranyl acetate	1381	1379	0.37	-	0.22
β-elemene	1390	1389	0.28	-	0.18
trans-farnesene	1454	1454	0.34	-	-
β-selinene	1492	1489	0.17	-	-
γ-cadinene	1511	1513	0.31	0.12	0.18
caryophyllene oxide	1583	1582	1.29	-	0.15
globulol	1592	1590	0.19	-	-
β-eudesmol	1652	1649	0.66	-	-
α-sinensal	1751	1755	0.26	0.17	-
Hydrocarbon monoterpenes			78.31	94.85	90.13
Oxygenated monoterpenes			15.47	3.53	6.40
Hydrocarbon sesquiterpenes			1.10	0.12	0.36
Oxygenated sesquiterpenes			2.40	0.17	0.15
Not identified			2.75	1.33	2.82

[1] - Linear retention index calculated with the retention times of a C8 – C30 alkane standard. [2] - Linear retention index reported in the literature (Adams, 2017). Source: authors (2021).

According to Table 3, peel essential oil from fruits whose scions were grafted on 'Carrizo' citrange rootstock had the highest number of identified compounds (30), followed by trifoliate orange (20), and 'Swingle' citrumelo (19). Unlike the major compounds, which are mainly influenced by genetic factors, the presence and content of minor compounds are more prone to changes by edaphoclimatic factors and by rootstock kind since the pair rootstock/scion may interact differently according to their own matching and environmental factors acting on the plant (EFROM; SOUZA, 2018; LURO *et al*., 2020).

Referring to chemical classes, it was noteworthy that fruit peel essential oil from the plants grafted on 'Carrizo' citrange presented a higher number of oxygenated monoterpenes (15.47 wt.%), about two and three times the amount observed in the oil of trifoliate orange (6.40 wt.%) and 'Swingle' citrumelo (3.53 wt.%), respectively. The same behavior was observed for the other chemical classes (hydrocarbon and oxygenated sesquiterpenes).

Tao *et al*. (2008) reported that monoterpene hydrocarbons accounted for 86.62 wt.% of peel essential oil of 'Okitsu' satsuma mandarins from Mainland China. Cano and Bermejo (2011) commented that, for peel essential oil of 'Owari' satsuma mandarins, hydrocarbon monoterpenes were the main chemical class, accounting for more than 95 wt.% of total oil composition, independently of the rootstock type. Song et al. (2006) reported, for peel essential oil of Shiranui mandarin (a hybrid of C. *unshiu*), hydrocarbon monoterpenes as the main chemical class (>90 wt.%), with small amounts of oxygenated monoterpenes (approx. 5 wt.%). Luro *et al*. (2020) cited that, for mandarins, fruit peel oil is mainly (>90 wt.%) composed of monoterpenes (limonene and pinenes), with a small contribution of other chemical classes. The exceptions are some varieties of *C. deliciosa* (Mediterranean mandarin), whose peel essential oil may have methyl N-methylanthtranilate in contents up to 20 wt.%.

Conclusions

Plants grafted on trifoliate orange rootstock presented smaller and lighter fruits, with higher titratable acidity and lower ratio values. The trifoliate orange rootstock has had the highest essential oil yield, whereas the lowest was the 'Carrizo' citrange. All peel essential oils presented limonene as the major compound, and p-cymene and linalool as secondary major compounds. The rootstock had an influence only on linalool content. The essential oil from 'Carrizo' citrange rootstock had the highest linalool content, whereas 'Swingle' citrumelo has had the smallest one. Relative to fruit quality, all rootstocks have had a similar performance from an economic standpoint. Considering essential oil content and yield, higher linalool contents are of interest for industry, thus, the 'Carrizo' citrange may be an interesting rootstock option for 'Okitsu' Satsuma mandarins.

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