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Rootstocks' effects on yield, fruit characteristics, and juice quality of the Tunisian Maltese half-blood (*Citrus sinensis* L. Osbeck): an important citrus cultivar

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Abstract— *In recent years, international trade in Maltese half-blood (Citrus sinensis) has increased. The rootstock's potential defines the fruit's characteristics in the eco-system where it is developed. As a result, in order to achieve the demands of the Maltese half-blood fruit market, it is critical to understand the effects of the rootstock and its role in fruit and juice quality. The Maltese half-blood was grafted onto four rootstocks and the fruit and juice quality parameters were evaluated. The obtained results revealed that rootstocks have a significant impact on the peel tickness of the fruits, as well as the acidity and total soluble solids of the juices. Indeed, the rootstocks significantly impacted the quality of the fruits and the juices in their environment. It was found that C35 citrange is a good rootstock for Maltese half-blood variety. Therefore, these on-site rootstock evaluation effects should assist local farmers in selecting the best rootstocks for their Maltese half-blood citrus cultivar based on the cultivation site's specific climatic and edaphic conditions.*

Keywords— ***Citrus sinensis, Maltese half-blood, rootstock, fruit quality, juice properties.***

I. INTRODUCTION

Citrus, a genus in the Rutaceae family, contains several important fruits, including oranges, mandarins, limes, lemons, sour oranges, and grapefruits [1]. Citrus fruits are an important horticultural crop. Indeed, citrus species are among the world's most important fruit crops [2]. Citrus fruits are primarily grown along the coasts of many countries, as well as in the Mediterranean region. In 2018, more than a million tons were produced on 1.2 million hectares, primarily in India, Mexico, China, Argentina, Brazil, Turkey, and Spain, according to the latest report of the Food Agriculture Organization [3].

Tunisia is well known for its significant citrus fruit production. On a national scale, the citrus fruit sector is important in Tunisia in terms of agro-economic importance [4], with an area of 19203 hectares [5]. This crop resulted in an average annual production of 109000 tons in 2020. Its cultivation area was increased from 22016 hectares in 2009 to 28062.3 ha in 2020 because these trees with juicy fruits have adapted beautifully to the Mediterranean climatic conditions [5].

Maltese is grown on 19203 hectares in the Cap Bon region, accounting for 68.42% of the total citrus orchard area. Cap Bon accounted for 68.42% of total citrus production. Bizerte, Ben Arous, and Kairouan account for the remaining 31.58% of citrus production [5].

In Tunisia, Maltese production accounted for 87.64% of total citrus exportation to several countries, including France, which ranked first in selling the Maltese (57.74%), followed by Italy (13%), and Germany (13%) [5].

Apart from its importance in the Tunisian agro-economy, Maltese has been reported to be a good source of vitamins known for their health benefits and protective effects against chronic diseases, implying their medicinal properties [4]. Indeed, Maltese half-blood oranges are distinguished by their high content of phenolic compounds that, in addition to giving the fruit its distinctive color, are linked to health benefits 'properties due to their antioxidant potentialities [6].

Furthermore, Maltese fruits are well-known for their flavor and nutritional value [7, 8, 9]. Due to its excellent sugar-acid balance and exceptional sensory profile, the 'Maltese half-blood' variety, known as "the queen of oranges," is regarded as the best sweet orange in the world [10].

The product "fruit" must be of high quality as dictated by the merchandising requirements [11]. This significant request imposed the need for research into the advancement of the technological package, particularly the rootstocks, which are critical in citrus production.

In the citrus industry, improving fruit quality and agronomic performance has been a major breeding goal [12]. Rootstocks have had a major impact on global progress of the citrus industry. In many citrus-producing areas, the effect of rootstocks on citrus fruit production and fruit quality has been extensively studied [13]. Whereas most research findings on rootstocks have focused on vegetative growth, yield, and sensibility to damage by abiotics and biotics under various environmental conditions, some investigations have focused on the effect of rootstocks on fruit quality [14, 15, 16, 17, 18]. The findings of these studies revealed varying results and inconsistent conclusions, which were attributed to a variety of factors, such as environmental factors, climatic conditions, and soil characteristics. As a result, it is risky to apply rootstock recommendations from one part of the world to another without first conducting a thorough evaluation locally [19, 20].

Because environmental factors and agronomic practices vary greatly from region to region, this scientific work was conducted to determine the impact of four commercial rootstocks on Maltese half-blood orange (*Citrus sinensis*) trees grown in the Cap Bon region. To gain a better understanding of how rootstock affects citrus fruit quality, fruit samples were collected from each rootstock in order to evaluate fruit and juice quality. Fruit weight, fruit diameter, peel thickness, juice yield, total soluble solids, or Brix, and titratable acidity were all evaluated. Subsequently, the sensory profiles of fruits and juices were investigated. A descriptive sensory analysis was carried out to elucidate the rootstocks' effects on organoleptic properties.

II. MATERIAL AND METHODS

Chemicals

All solvents used in the experiments were purchased from Merck (Darmstadt, Germany). All chemicals used were of analytical grade.

Experiemental area

The current research was conducted at the Tunisian Citrus Fruits Technical Center. It is located in the Beni Khaled region of Tunisia's northeast (36°37'49.7"N, 10°33'32.2"E, with a mean elevation of 49 m above sea level) and has a semi-arid bioclimatic stage with mild winters.

Plant material and experimental design

Our research was conducted with ripe fruits of the Maltese half-blood orange (Citrus sinensis L. Osbeck) cultivar on four rootstocks. The rootstocks used were Sour orange (Citrus aurantium L.), Swingle Citrumelo 4475 (Citrus paradisi Macf × Poncirus trifoliata L. Raf.), Volkameriana Citrus (Citrus limonia Osbek), and C35 Citrange (Citrus sinensis ruby blood x Poncirus trifoliata L. Raf.). The experimental design consisted of a randomized complete block design with three replicates and a Maltese half-blood orange on one rootstock per block. Trees, aged 3 years, were spaced 6 m x 3 m apart and subjected to the same cultural practices.

Yield

Fruits from each tree were collected and weighed separately so that the yield per tree (Kg) could be calculated. Therefore, the trees were categorized into 3 classes: C_1, C_2, and C_3 according to the number of fruits per tree.

Class C_1: number of fruits > 50

Class C_2: 20 < number of fruits < 50

Class C_3: number of fruits < 20

Fruit parameter evaluation

For the measurements of technological characteristics, 5 fruits per tree, for a total of 20 fruits per bloc, were randomly chosen. Fruit weight, equatorial and transverse diameters, peel thickness, and juice yield were evaluated. Citrus fruits were used to extract juice, which was accomplished using a citrus fruit press and used to evaluate juice yield.

Juice parameter evaluation

Titrable acidity

The titrable acidity was determined using the method described by Giuffrè et al. [21]. The juice was neutralised by a NaOH solution (0.1 mol. L^{-1}) and some drops of phenolphthalein as an indicator solution. Indeed, under neutral conditions, the NaOH solution turns the juice pink. The juice acidity is expressed in grams of citric acid per litre of juice. In other words, it is also expressed by the millilitres of NaOH (0.1 mol. L^{-1}) having neutralised 5 mL of juice. According to the equation nava nbvb, where na is the normality of the acidic solution (juice), nb is the normality of the NaOH (0.1 mol. L^{-1}), va is the volume of the acidic solution (juice), and vb is the volume of the solution of NaOH (0.1 mol. L^{-1}), the titrable acidity was estimated according to the following formula:

Titrable acidity (g. L^{-1}) = $n_a = n_b v_b$ (mL) M/V_a (mL) x $P_{protons}$

Where M is the molecular weight of the citric acid (192 g), and $P_{protons}$ is the number of H+ protons carried by the citric acid.

Total soluble solids

Total soluble solids content was determined by taking a direct reading with a Brixstix (BSR100) refractometer (UK).

Sensory evaluation

A trained sensory panel (comprising sixteen expert tasters from the citrus technical center) evaluated oranges and juices at the National Institute of Agronomy's sensory analysis laboratory. The experiment was carried out in a normalized tasting laboratory with normalized sensory cabins. Oranges and juices were served in odor-free plastic material coded with 3-digit numbers. The panel looked at the following properties: (i) color, odor, form, peel, texture, aromatic notes, and taste of the fruit; (ii) color, odor, and taste of the juice (bitterness, sweetness, astringency, and acidity) [22]. Each panelist assessed the various attributes of the samples according to an unstructured 10 cm linear scale for each attribute. The scale ranged from "very weak" to "very strong," and sensory data was recorded as distances (cm) from the origin [23].

Statistical analysis

The results were submitted for analysis of variance (ANOVA) using the SPSS software version 20.0 for Windows. The differences between the averages were tested using the Tukey test, and values with $P < 0.05$ were considered significantly different.

III. RESULTS AND DISCUSSION

Yield

The rootstock had an effect on the fruit yield. The differences in yield among rootstocks and their interactions with citrus cultivar could be attributed to differences in rootstock morphology and physiology, which are reflected in yield [24, 25, 26, 27]. The highest cumulative yield of ‘Queen’ orange was obtained from the trees on Swingle citrumelo and C35 Citrange, while the trees on volkameriana citrus and sour orange had the lowest yield. Trees budded on Swingle Citrumelo and C35 Citrange produced more than those budded on the other rootstocks. On Maltese half-blood, the yield of C35 Citrange was approximately 2.6 Kg. The yield of the trees grown on Sour orange and Volkameriana citrus was found to be in the 2.3 Kg range. Trees grafted onto Sour orange produced the highest proportion of class C2 fruits, ranging from 20 to 50 per tree. Only 11% of the trees in this association belong to class C1, with more than 50 fruits per tree. The Maltese half-blood orange/Volkameriana citrus association had the highest proportion of the C3 class (Fig. 1). These results revealed that the potential for fruiting depends on the compatibility between rootstock and cultivar. Greater fruit yield was also observed for Olinda valencia and Parent Washington navel oranges when swingle citrumelo was used as a rootstock [28, 29]

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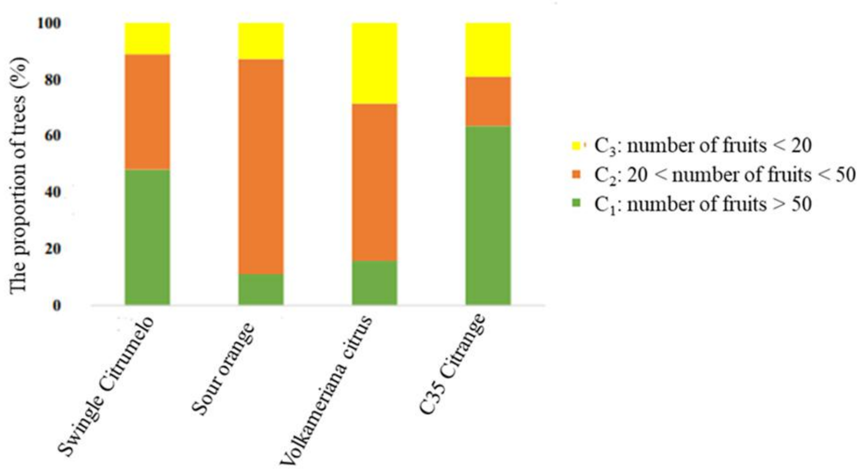

Fig 1. Effects of rootstocks on the yield

Evaluation of fruit parameters

Fruit weight

The average weight of fruits from trees on C35 Citrange was significantly higher than fruits from trees on other rootstocks ($P < 0.05$). In addition, fruits from trees on C35 Citrange were significantly bigger than those budded on Swingle Citrumelo, Volkameriana citrus, and Sour orange. The fruits of trees harvested from grafted trees on the C35 citrange have the heaviest weight, averaging around 204.85 ± 27.38 g. On the other hand, the fruits harvested from trees grafted onto Volkameriana citrus have the lowest weight, which is around 152.39 ± 15.11 g (Table 1). Previous scientific studies have reported the importance of rootstock in enhancing the fruit size of citrus [30, 31, 32, 33].

Fruit diameters

Fruit size is generally negatively correlated to the number of fruits per tree [34]. The larger and heavier the fruits are, the fewer there are on the tree. Furthermore, aside from fruit load, the ultimate size of a citrus fruit is determined by a variety of complex factors such as agronomic practises, climatic conditions, and the rootstock/scion combination. Large fruit sizes are popular in the fresh fruit market and command higher prices early in the season. The research found a significant difference in the transverse diameters of uits ($P < 0.05$). In addition, the study carried out revealed that the rootstock has a significant effect on the equatorial diameter of the fruits of the Maltese half-blood variety ($P < 0.05$). Indeed, the Maltese half-blood/C35 Citrange cross has the highest equatorial diameter, which is around 7.06 ±0.38 cm, and induces the highest transverse diameter, which is equivalent to 7.20 ± 0.43 cm. The smallest equatorial diameters are found in fruits from trees grafted onto Volkameriana citrus (6.42 ± 0.34 cm) and Sour orange (6.68 ± 0.35 cm) (Table 1).

Peel thickness

Regardless of the fact that Maltese half-blood oranges are often available for consumption as juice, there is a growing market for fresh fruit. So, in addition to internal fruit color, consumers expect other quality attributes. Peel thickness is one of these parameters that can be a limiting factor in commercializing oranges [35]. Indeed, peel thickness, firmness, or texture is a determinant of citrus freshness [32]. Peel thicknesses at either extreme are undesirable. Fruit with a thick peel is typically low in juice, whereas fruit with a thin peel is more prone to splitting and postharvest problems that can occur during shipping and storage. The rootstock had an effect on peel thickness as well ($P < 0.05$). The greatest peel thickness is found in the fruits of trees grafted onto Sour orange and C35 Citrange, which have a diameter of 0.54 ± 0.06 cm and 0.51 ± 0.04 cm, respectively (Table 1). On the other hand, the fruits of the combination of Maltese half-blood and Citrumelo Swingle have the thinnest peel thickness, which is around 0.35 ± 0.01 cm. Sour orange induce thick peels, which makes it the better rootstock for fresh cumsuption. However, Swingle Citrumelo induces thin-peeled fruit, which makes it the better rootstock for juice production. This effect was also reported for Allen Eureka cultivated in Saudi Arabia [32]. According to the scientific litterature on rootstocks'effects, Macrophylla, Volkameriana, and Rough lemon produced the thickest peel [19, 29, 32, 36]. Rootstock Cleopatra produced the thinnest peel [19, 29, 32, 37].

The peel is the first fruit barrier against abiotic and biotic factors that can contribute to fruit quality damage during the preharvest and postharvest periods. As a result, when investigating the impact of rootstock on citrus fruit quality, peel thickness is usually taken into account. However, the juice content of such fruits is typically lower. As a result, fruits with thicker rinds would be less important in fruit destined for juice production than those destined for fresh consumption. Several studies have found that the effect of rootstock on peel thickness varies greatly depending on the cultivar under consideration. Nonetheless, some rootstocks have the same effect on peel thickness across all varieties. It is also worth noting that in some studies that provided repeated results for different seasons, differences between rootstocks observed in one season were not observed in the following season [38].

Juice yield

Citrus fruit juice yield is an important quality parameter [27]. As a result, it is necessary to take into consideration specific rootstocks' power to improve juice yield. Therefore, it is critical to consider the ability of specific rootstocks to increase juice yield. Juice content was a remarkable trait for all rootstocks, as they all met the international market's minimum requirement of 42%. The statistical analysis demonstrated that the rootstocks have no significant effect on juice yield (Table 1). Similar findings were reported by Bassal [25], who discovered that rootstock variation had no effect on citrus juice yield. Despite the fact that there was no statistically significant difference in juice content between rootstocks, fruits from trees on C35 Citrange had a higher juice content, which makes it an ideal rootstock for juice production. Fruits from Sour orange grafted trees had lower juice content. These results corrolated well with the peel tickness estimation. The influence of rootstock on juice content has been related to the inherent rootstock differences that affect plant water uptake.

Table 1: Effect of Rootstocks on yield and fruit quality of the Tunisian "Maltese half-blood"

Rootstock	Fruit weight (g)	Fruit diameters (cm)		Peel thickness (cm)	Juice yield (%)
		Equatorial diameter (cm)	Transverse diameter (cm)		
Swingle Citrumelo	138.52 ± 30.35bc	6.78 ± 0.50ab	6.82 ± 0.49ab	0.35 ± 0.01a	58.75 ± 4.53a
Sour orange	172.65 ± 19.91ab	6.68 ± 0.35ab	6.70 ± 0.39a	0.54 ± 0.06c	51.51 ± 3.84a
Volkameriana citrus	152.39 ± 15.11a	6.42 ± 0.34a	6.45 ± 0.38a	0.44 ± 0.05b	59.38 ± 1.98a
C35 Citrange	204.85 ± 27.38c	7.06 ± 0.38b	7.20 ± 0.43b	0.51 ± 0.04c	55.82 ± 5.27a

Means with different letters within a line are statistically different.

Different letters indicate significant differences ($P < 0.05$) according to Tuckey’s multiple range test

Juice parameter evaluation

Total soluble solids

Citrus fruit flavor and palatability are determined by the relative levels of soluble solids, acids, and the presence or absence of various aromatic or bitter juice constituents [39]. Rootstocks were found to affect the soluble solids concentration in fruit juice ($P < 0.05$). In terms of total soluble solids, Swingle Citrumelo (11.63 ± 0.39 g. L^{-1}) demonstrated the highest content of total soluble solids, followed by Sour orange (9.34 ± 0.62 g. L^{-1}), C35 Citrange (9.02 ± 0.94 g. L^{-1}), and Volkameriana citrus (8.33 ± 0.57 g. L^{-1}) (Table 2). These findings are consistent with those of Zekri and Aljaleel [29], who revealed that the sugar content of fruits from grafted trees on Sour orange was higher than that of fruits from grafted trees on Volkameriana citrus. In the same context, Hifny et al. [40] found that grafting Washington Navel oranges onto rootstock Sour Orange produced fruit with higher total soluble solids than grafting them onto rootstock Volkameriana. This effect was recently reported in a study on six rootstocks on Lane Late and Delta oranges (17).

Titrable acidity

Citrus juice total acidity is an important factor in overall juice quality [32]. In this study, the rootstocks had an effect on the acid content of the juice. Indeed, the results obtained show a significant difference depending on the rootstocks

($P < 0.05$). The use of sour orange as a rootstock allows for a higher titratable acidity (Table 2). The acidity value reached 1.30 ± 0.02 g. L^{-1}.

The acid content is an important quality parameter that strongly influences the flavor of citrus fruit. Whereas the impact on titratable acidity is dependent on rootstock/scion combination some rootstocks have been demonstrated to provide the same influence on multiple varieties. This occurred with Sour orange, which has been shown to increase titratable acidity levels in various citrus species scions by delaying commercial maturity when compared to other rootstocks.

Table 2: Effect of Rootstocks on juice quality of the Tunisian "Maltese half-blood" oranges

Rootstock	Acidity (g. L^{-1})	Total soluble solids (g L^{-1})
Swingle Citrumelo	1.25 ± 0.03ab	11.63 ± 0.39b
Sour orange	1.30 ± 0.02c	9.34 ± 0.62a
Volkameriana citrus	1.11 ± 0.10a	8.33 ± 0.57a
C35 Citrange	1.22 ± 0.07ab	9.02 ± 0.94a

Means with different letters within a line are statistically different.

Different letters indicate significant differences ($P < 0.05$) according to Tuckey's multiple range test.

Rootstock disparities that affect plant water relations have been associated with the impact of rootstock on sugars and acid content. The increased the scion-photosynthetic rootstock's potential, the more carbohydrate compounds are transmitted from leaves to fruits [41]. The greater the photosynthetic capacity of the scion-rootstock, the more carbohydrate compounds are transported from leaves to fruits [42, 43]. Moreover, carbohydrate concentration in fruit has been connected to vascular resistance to sugars transfer at the rootstock's budding union [44]. As a result, reduced photoassimilate translocation from leaves to roots limits root development while also making these compounds more available in the scion, resulting in increased carbon transport toward fruit [45, 46].

Based on the findings of the study, a summary table of rootstock classification based on measured parameters has been created. If the rootstock provides the highest value, we note (+2). If the rootstock provides an intermediate value, we note (+1). If the rootstock produces the lowest value, we record 0. Then, we ranked the rootstocks in ascending order by adding the scores awarded. The results of the study indicated that the best outcomes were obtained for the C35 Citrange rootstock (Table 3).

Table 3. Rootstock classification based on measured parameters

Rootstock	Yield (Kg/tree)	Fruit weight (g)	Fruit diameters (cm)		Peel thickness (cm)	Juice yield (%)	Acidity	Total soluble solids	Total
			Equatorial diameter (cm)	Transverse diameter (cm)					
C35 Citrange	+2	+2	+2	+2	+1	+2	+1	+2	14
Sour orange	+1	+1	+1	+1	+2	0	+2	+1	9
Citrumelo Swingle	+1	+1	+1	+1	0	+1	+1	+1	9
Volkameriana citrus	0	0	0	0	+1	+1	0	0	2

(+2): rootstock provides the highest value.

(+1): rootstock provides an intermediate value.

0: rootstock provides lowest value.

Sensory evaluation

Sensory profile of fruits

Oranoleptic properties are critical in fruits destined for fresh consumption. Indeed, a fruit's appearance (associated with its color and visual defects), as well as its sensory quality (sweetness, acidity, astringency), texture (firmness, roughness, and defects in touch), and fruity are the main determinants of buying behavior and thus the consumer's perception of fruit quality [47]. Nonetheless, because the rootstock effect on fruit quality is scion-dependent, it is necessary to investigate the rootstock effect on the cultivar of interest. Despite the fact that rootstocks have significant effects on tree vigor and yield, very few studies have focused on their impact on organoleptic properties of specific citrus cultivars.

The descriptive sensory analysis revealed the impact of the tested rootstocks on the sensory profile of Maltese half-blood oranges (Fig. 2). The perception differences are related to the specific effects of different rootstocks on total soluble solids and acidity levels, as well as the aroma volatile compound content.

The results revealed that the oranges from Maltese half-blood/Swingle Citrumelo and Maltese half-blood/Sour orange had the most intensely colored peels ($P < 0.05$). The color of citrus peel is caused by the accumulation of three types of pigments: chlorophylls, carotenoids, and anthocyanins [48]. Swingle Citrumelo and Sour orange induced the most intensely colored peels. This variation in citrus peel color might be related to the effect of rootstock on pigment concentration, as explained in numerous research studies [27]. Sugar levels have been linked to color intensity in citrus peel [49, 50]. These findings support previous research on the effects of carbohydrates, particularly hexoses, on the inhibition of genes encoding chlorophyll and photosynthesis process [51, 52]. As mentioned in the total soluble solids section, Swingle Citrumelo and Sour orange rootstocks have a significant impact on the total soluble solids and, thus, on the sugar levels in citrus fruit.

Despite having the lowest color intensity, the Maltese half-blood/C35 Citrange combination has the most uniform color distribution across the entire surface of the peel. The fruits from the various rootstocks have a prickly texture and a rounded shape, with tasters discovering that those from the half-blood/swingle Citrumelo combination have the most regular shape. The Maltese half-blood/(C35) Citrange oranges were deemed the easiest to peel by the tasters. The fruits of the Maltese half-blood/Swingle Citrumelo cross ranked first in terms of fiber content.

The influence of rootstocks was different between peel and pulp color. The fruits of trees grafted onto Volkameriana citrus have the most intense colored pulp. Similar results were recorded by Incesu et al. [53]. The authors studied the effects of six rootstocks on Moro blood oranges and discovered that the red color peel was significantly high in fruits from Carrizo Citrange and Troyer Citrange, while the pulp color was greatest in fruits from Yuzu and Cleopatra.

Fruits from C35 Citrange grafted trees are more acidic and less sweet, according to tasters. Fruits with a more fruity flavor, according to tasters, come from the combination of Maltese half-blood/Sour orange, followed by Volkameriana citrus and swingle citrumelo. Citrus fruit flavor is derived from a combination of taste and aroma sensations, with the sweet and sour taste attributes primarily governed by the presence of sugars and acids in the juice sacs, and the aroma of the fruit evolving from a mixture of dozens of volatiles that provide various fruity, floral, and other notes [23]. Fruit aroma and juice fruitiness are caused by volatile compounds such as terpenic hydrocarbons and oxygenated compounds. The monoterpene limonene is the principal volatile compound in all citrus fruit [54].

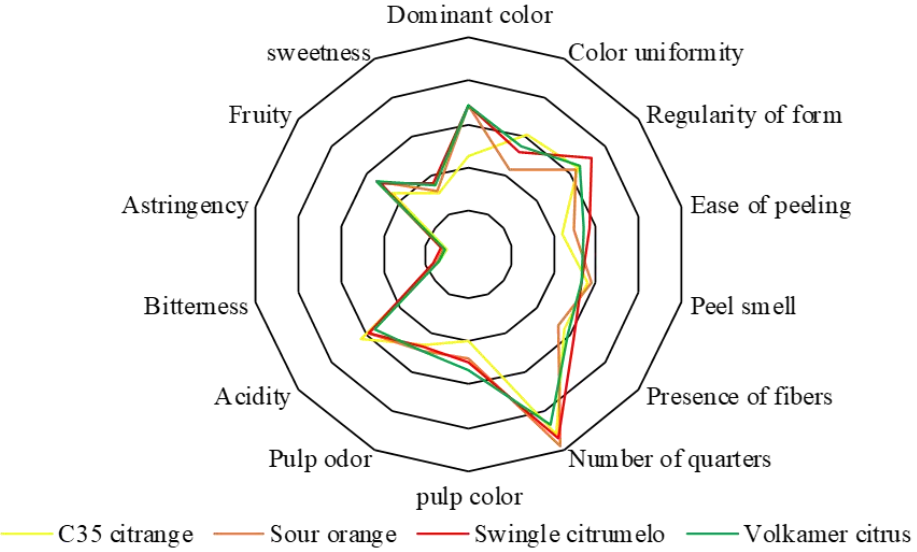

Fig 2. Descriptive sensory profile of citrus fruits as evaluated by a trained sensory panel

Sensory profile of juices

Organoleptic evaluation is an integral part of both new product development and food quality control in agrofood industry. Because of its sensory properties, orange juice is one of the most popular and consumed juices in the world. Juice sensory quality is determined by complex sensations caused by the interaction of various senses (fruity, taste, and color) [55].

Color has been identified as influencing consumer acceptance as one of the main qualitysensory attributes valued by consumers [56]. Figure 1 depicts the average scores for each evaluated attribute using a radial chart (Fig 3). The sensory evaluation results showed that orange juice from trees grafted onto the Sour orange has a more intense color than orange juice from other rootstocks ($P < 0.05$). On the other hand, the trees grafted onto C35 Citrange produced fruits with a lighter juice color and less pulp. According to the tasters, the orange juices of the Maltese half-blood combination with Swingle Citrumelo and the Maltese half-blood combination with Volkamer citrus have a similar fruity. In terms of acidity, the orange juices from the Maltese half-blood/Sour orange and Maltese half-blood/Volkamer citrus associations had identical notes, and the Maltese half-blood/C35 association had the highest score among the rootstocks..

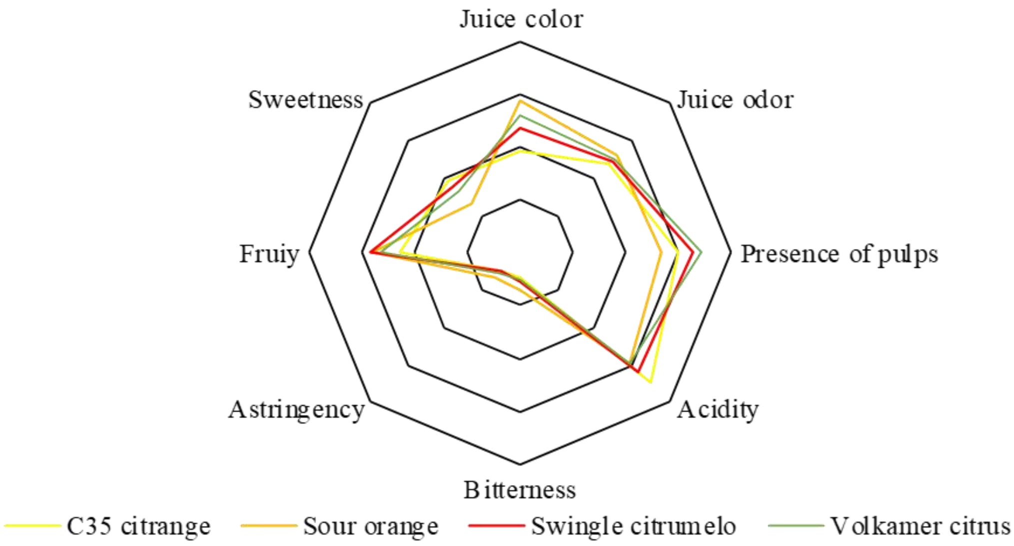

Fig 3. Descriptive sensory profile of juices as evaluated by a trained sensory panel

IV. CONCLUSION

The evaluation of suitable rootstocks has recently been addressed in a variety of crops, including citrus fruit. The studies have mainly focused on tree vigor, precocity, productivity, and disease resistance. However, the selection of rootstock has an impact on both external and internal quality parameters. Indeed, selecting the best rootstock is critical because the scion/rootstock interaction impacts yield, fruit and juice quality attributes. These conditions also differ depending on the region. Therefore, these on-site rootstock evaluation effects should assist local farmers in selecting the best rootstocks for their Maltese half-blood citrus cultivar based on the cultivation site's specific climatic and edaphic conditions. The study found that rootstocks had a major effect on most of the parameters measured, implying that rootstock selection can affect yield, and fruit quality in 'Queen' orange trees. It was found that C35 citrange is a good rootstock for Maltese half-blood variety. Nonetheless, it is worth noting that, in addition to rootstock, the effects could be impacted by agroclimatic conditions and agricultural practices. More research is needed to determine the molecular mechanisms involved rootstock-induced effects on fruit quality.

AUTHORS' CONTRIBUTIONS

This work was carried out in collaboration among all authors. Asma Mami Maazoun and Oumayma Zerai contributed equally to this work.

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