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Crop yield and physical and chemical characteristics of acerola clones grown in the Alta Paulista region, Brazil

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Abstract
This paper aimed to evaluate crop yield and physical and chemical characteristics of acerola (*Malpighia emarginata* Sessé & Mociño ex DC) clones grown in the Alta Paulista region, Brazil. The evaluation comprised 7 clones, namely: Olivier, BRS 238-Frutacor, BRS 236-Cereja, BRS 235-Apodi, BRS 237-Roxinha, Okinawa, and Waldy-CATI 30, studied from October 2018 to April 2019. Crop yield was analyzed based on the accumulated production of 12 harvests, with fresh mass expressed in kg fruit·plant^{-1}. Considering the capacity of 30 harvests per plant within the complete cropping period, total fruit mass (in kg fruit·plant^{-1}) and crop yield (in t ha^{-1}) were estimated. Samples were collected from 4 of the 12 harvests in order to determine average fruit mass (g); average fruit size, fruit height/diameter ratio, and pulp yield (%). Regarding fruit pulp, the analysis consisted of quantifying the soluble solids, expressed in degrees Brix, and the technological index (i.e. pulp yield x °Brix/100). The experiment was conducted in a randomized block design, with 7 treatments and 4 repetitions. The obtained data were statistically processed by analysis of variance using the F test, and the means were compared using the Tukey's test at the 0.05 significance level. The study concluded that, given the soil and weather conditions of the Alta Paulista region, Olivier, Apodi and Frutacor are the clones mainly recommended for the agro-industrial market, being the Olivier cultivar the first option among the three and appearing in a greater proportion in the area of the commercial orchard studied. Regarding the acerola production for fresh consumption, Olivier and Roxinha are the most suitable clones. Olivier stands out for its good fruit yield, adequate physical and chemical characteristics, and easy manual harvesting.
Keywords: *Malpighia emarginata* Sessé e Mociño ex DC´; tropical fruit growing; fruit crop production; post-harvest.

Produtividade e características físico-químicas de clones de acerola cultivados na região Alta Paulista

Resumo
Objetivou-se avaliar a produtividade e características físico-químicas de clones de acerola cultivados na região Alta Paulista. Avaliou-se 7 clones: Olivier, BRS 238-Frutacor, BRS 236-Cereja, BRS 235-Apodi, BRS 237-Roxinha, Okinawa e Waldy-CATI 30, no período de outubro de 2018 a abril de 2019. Analisou-se produção acumulada de 12 colheitas, sendo expressa a massa fresca em kg de frutos.planta^{-1}. Seguindo a premissa de 30 colheitas por planta ao longo de uma safra completa, estimou-se a produção total de frutos em kg frutos planta^{-1} e a produtividade em t ha^{-1}. Em 4 das 12 colheitas, foram retiradas amostras para avaliação da massa média do fruto (g); tamanho médio do fruto, relação altura:diâmetro e rendimento de polpa (%). Na polpa foram quantificados os sólidos solúveis expressos em ° Brix e o índice tecnológico (rendimento de polpa x °Brix/100). Como delineamento experimental utilizou-se blocos ao acaso, com 7 tratamentos e 4 repetições. Os dados foram submetidos à análise de variância para o Teste F e as médias comparadas pelo Teste Tukey ao nível de 5% de significância. Concluiu-se que nas condições de clima e solo da região Alta Paulista recomenda-se o plantio dos clones Olivier, Apodi e Frutacor principalmente visando o mercado agroindustrial, sendo o clone Olivier a primeira opção e em maior proporção na área de implantação do pomar comercial. No cultivo de acerola voltado para consumo in natura indicam-se clones

Olivier e Roxinha. O clone Olivier se destaca pela boa produtividade, características físico-químicas adequadas e facilidade de colheita manual dos frutos.
Palavras-chave: *Malpighia emarginata* Sessé e Mociño ex DC; fruticultura tropical; sistema de produção de frutíferas; pós-colheita.

Introduction

The production and consumption of acerola (*Malpighia emarginata* Sessé & Mociño ex DC) in Brazil has been encouraged for the reason that it is considered a functional food with high levels of ascorbic acid, an essential dietary component (ASENJO; FREIRE DE GUZMAN, 1946), which is not synthesized by the human organism (CHITARRA; CHITARRA, 2005; MACIEL *et al*., 2010). The fruit has significant nutritional value (MERCALI *et al*., 2013), high total antioxidant capacity and high levels of phenolic compounds (RUFINO *et al*., 2009; MARIANO-NASSER *et al*., 2017), in addition to anthocyanins and carotenoids (MUSSER *et al*., 2004; LIMA *et al*., 2014).

It is noteworthy that the varieties of acerola may contain different pulp concentrations and compositions due to intrinsic factors such as the cultivar in itself, external appearance, and maturity stage; as well as extrinsic factors such as weather conditions and nutrient levels in the soil of the crop area (MELO *et al*., 2008; PEDÓ *et al*., 2014).

This tropical fruit-bearing shrub, or small tree, can be an excellent source of income for family farming, since there are several harvests during the cropping period. As harvesting is done manually, the process demands a sustained period of labor for months (NASSER *et al*., 2018).

In Brazilian soils, the production of acerola predominates the in Northeast region. The most common acerola clones grown in the states of Minas Gerais, Sergipe, Bahia and Pernambuco are: Sertaneja, Flor Branca and Okinawa. In the state of São Paulo, the clones most commonly grown are Olivier and Waldy-CATI 30 (RITZINGER; RITZINGER, 2011; FURLANETO; NASSER, 2015).

Although the literature contains some characterization of the acerola fruit, few studies indicate the cultivars and the crop yields thereof. In view of that, the current paper aimed to evaluate fruit crop yield and physical and chemical characteristics of acerola clones grown in the Alta Paulista region, Brazil.

Material and Methods

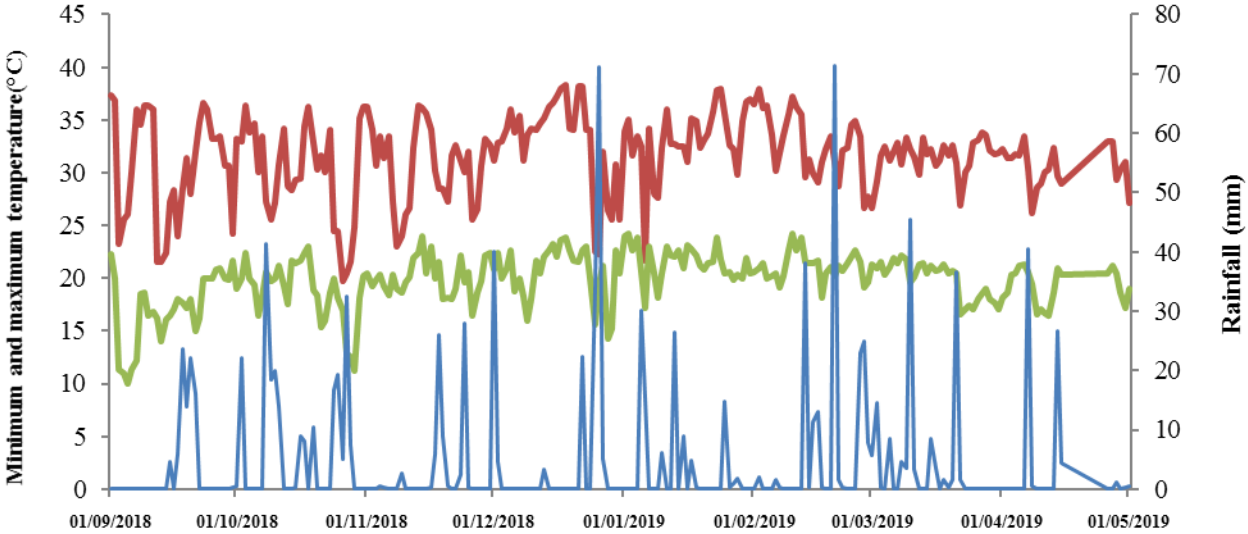
For the experiment, the harvests of ripe acerola fruit (*Malpighia emarginata* Sessé & Mociño ex DC) took place from October 2018 to April 2019, in the morning, manually, with a full count of 12 harvests. Under field conditions, for the purpose of this study, the acerola fruit was considered ripe when its peel color was visually 75% red.

Seven clones, or cultivars, were evaluated, namely: Olivier, BRS 238-Frutacor, BRS 236-Cereja, BRS 235-Apodi, BRS 237-Roxinha, Okinawa, and Waldy-CATI 30. These comprised 12-year-old plants from the experimental orchard of the Alta Paulista regional growth pole of the *Agência Paulista de Tecnologia dos Agronegócios* (APTA – São Paulo's Agency for Agribusiness Technology), located in the municipality of Adamantina, state of São Paulo (SP), Brazil, at the coordinates 21°40' S, 51°08' W, and 400 m altitude.

The climate of the region is considered Cwa, humid subtropical, according to the Köppen classification; with hot and rainy summer, and dry and mild winter (HERRERA *et al*., 1997). The annual mean temperature is 22-23 °C, the hottest month reaching around 26 °C. The mean rainfall from 1960 to 2019 was 1,300 mm.

The soil of the growing site was classified as red-yellow Argisol, eutrophic, moderate A, sandy/medium texture, and undulating topography (SANTOS *et al*., 2006). The temperature and rainfall data of the entire experiment are shown in Figure 1, and were collected daily by the *Centro Integrado de Informações Agrometeorológicas* (CIIAGRO – Integrated Center for Agrometeorological Information).

Figure 1- Minimum and maximum temperature, and rainfall. Adamantina-SP, Alta Paulista region, Brazil.



Source: CIIAGRO (2013)

In terms of planting distance, the spacing between trees was equivalent to 6.00 m x 5.00 m, under rainfed farming. For weed control, the treatments underwent manual and chemical weeding. Based on chemical analysis of the soil, liming and mulching were also carried out, as recommended by Raij *et al*. (1997).

When all harvests had been completed, the following characteristics were analyzed: accumulated production of the 12 harvests, expressing fresh mass in kg fruit·plant^{-1}. Taking into consideration that during the entire cropping period there are 30 harvests per plant, and based on field observation by the authors since 2009, the total fruit mass (in kg fruit·plant^{-1}) was estimated using the mathematical rule of three. In this way, the crop yield estimate (in t ha^{-1}) was calculated by multiplying the kg fruit·plant^{-1} by the number of plants in the experiment site (333 plants ha^{-1}).

Samples from 4 of the 12 harvests were collected to determine: average fruit mass (g), obtained from 10 fruit in each experimental plot; average fruit size, using a digital caliper to measure height (mm) and diameter (mm) of 10 ripe fruit per plot, and the height/diameter ratio thereof; and pulp yield (%), calculated from 500 g of fruit from each plot, depulped in a centrifuge. For the pulp, the soluble solids (expressed in degrees Brix) were quantified using a portable refractometer. The technological index, which is a variable that indicates the quality of the fruit for industrial processing, was calculated using the formula: (pulp yield x °Brix)/100.

The experiment was conducted in a randomized block design, with 7 treatments and 4 repetitions. The obtained data were statistically processed by analysis of variance using the F test, and the means were compared using the Tukey's test at the 0.05 significance level.

Results and Discussion

The Olivier clone yielded 30.53 t ha^{-1}, almost 5 times more than Okinawa; however, it did not differ from the Frutacor and Apodi clones (Table 1). Olivier cultivar's superiority can be explained by the fact that it was selected from a commercial orchard located in Junqueirópolis-SP, a municipality with soil and weather conditions very similar to those in the present study, therefore demonstrating its good adaptation to the region. This clone has been cultivated in the Alta Paulista region for more than 20 years, and according to reports by local producers and the very creator of the material, Moacir Olivier, this acerola cultivar can produce more than 100 kg fruit·plant^{-1} throughout the cropping period, a value close to that found in the current study.

Table 1- Mean values for fresh fruit mass of 12 harvests, estimate of fruit mass per plant of 30 harvests, estimate of crop yield, and production index of acerola clones. Adamantina-SP, Alta Paulista region, Brazil, 2019

Clones	Fresh mass kg fruit·plant^{-1} (12 harvests)	Estimate of kg fruit·plant^{-1} (30 harvests)	Estimate of crop yield (t ha^{-1})*[2]	Production index (%)
Olivier	36.67 a*[1]	91.68 a	30.53 a*	100.0
Frutacor	27.46 ab	68.66 ab	22.86 ab	74.88
Cereja	15.27 cd	38.18 cd	12.71 cd	41.64
Apodi	30.08 ab	75.21 ab	25.04 ab	82.03
Roxinha	14.10 cd	35.25 cd	11.74 cd	38.45
Okinawa	8.22 d	20.56 d	6.85 d	22.42
Waldy	21.58 bc	53.96 bc	17.97 bc	58.85
Overall mean	**21.91**	**54.79**	**18.24**	**-**
F	**23.46****	**23.45****	**23.45****	**-**
CV (%)	**18.97**	**18.97**	**18.97**	**-**

*[1] Means followed by the same letter in the column do not differ by the Tukey's test at the 0.05 significance level. *[2] plant population: 333 plants ha^{-1}.

The Apodi and Frutacor cultivars also presented good fruit yields under rainfed farming. Over the studied period (September 1, 2018 to May 1, 2019), the total rainfall was 1087.3 mm.

Paiva (2003) reported yields above 40 t ha^{-1} for these clones in northeastern Brazil with 500 plants ha^{-1} under irrigation, a fact that highlights the good adaptation of these two cultivars to different growing environments.

Concerning the quality of the acerola fruit, it can be seen from Table 2 that there was no difference in average fruit mass or in fruit diameter, with an overall mean of 5.89 g and 23.17 mm, respectively. Despite these results, it was possible, with each harvest, to visualize greater predominance of acerola fruit in the clones Olivier, Waldy, Apodi and Cereja. This greater harvesting capacity implies a higher yield, hence a longer period of harvest labor, which is the most costly stage in the production process of this crop. The Frutacor clone, despite its good fruit yield, has the intrinsic characteristic of arranging leaves and branches in a way that makes it difficult to visualize the fruit during manual harvesting; the same was observed for the Okinawa and Roxinha clones.

The fruit height/diameter ratio in Table 2 demonstrates that the fruit showed differences in shape. The Frutacor cultivar produced significantly different fruit compared to the Waldy cultivar. In this regard, the closer the ratio value was to 1.00, the more the fruit presented an oval shape. This characteristic was evident in Frutacor and Roxinha. However, the lower the height/diameter ratio, the flatter the shape of the acerola fruit. The mean values found for the clones under study were similar to those reported by Lima *et al*. (2014), who studied 6 acerola genotypes and found a variation from 0.84 to 0.92, evincing that acerola is a subglobose drupe type fruit.

Table 2- Mean values for average fruit mass; fruit height and diameter; and the fruit height/diameter ratio of acerola clones. Adamantina-SP, Alta Paulista region, Brazil, 2019

Clones	**Average fruit mass (g)**	**Fruit height (mm)**	**Fruit diameter (mm)**	**Height/diameter ratio**
Olivier	4.90 a*	19.64 b	22.34 a	0.88 cd
Frutacor	5.62 a	20.86 ab	22.01 a	0.95 a
Cereja	5.60 a	19.56 b	22.51 a	0.88 cd
Apodi	5.85 a	19.94 b	23.22 a	0.86 de
Roxinha	6.78 a	22.54 a	23.78 a	0.92 ab
Okinawa	6.79 a	22.36 a	24.77 a	0.90 bc
Waldy	5.66 a	19.58 b	23.56 a	0.83 e
Overall mean	**5.89**	**20.64**	**23.17**	**0.89**
F	**1.99** ns	**8.77***	**2.42** ns	**25.00****
CV (%)	**16.45**	**4.31**	**5.34**	**1.74**

*[1] Means followed by the same letter in the column do not differ by Tukey's test at the 0.05 significance level.

Bearing in mind that most part of the acerola production in Brazil is destined for agribusiness, Table 3 shows significant differences between the clones in terms of fruit pulp yield, soluble solids, and the technological index (TI). In addition to lower pulp yield, the Waldy cultivar showed low soluble solids content for the fruit, which led to a lower technological index. It can be inferred that the fruit of this acerola cultivar is for fresh consumption, which requires studies on sensory evaluation and consumer acceptability, and that under the soil and weather conditions of the Alta Paulista region this cultivar is not recommended for commercial production for agribusiness.

It is worth stressing that, according to Semensato and Pereira (2000), the minimum technological index required for citrus corresponds to 4.4. It is also noteworthy that the technological index associates the juice yield with the percentage of total soluble solids, which is a strong indicator of the final product yield in the industry. Thus, the higher the technological index, the better the fruit for industrial processing.

It should also be noted that the acerola fruit presents a juice yield between 49% and 75% of its weight, and with high acidity (pH 3.3). The water content in the fruit is on average 90%. The industries demand fruit whose peel color is more than 80% rosy to red, with more than 15 mm in diameter, minimum weight of 4 g/fruit, with good firmness and absence of damage (LIMA *et al*., 2014).

Table 3- Mean values for fruit pulp yield, soluble solids, and technological index of acerola clones. Adamantina-SP, Alta Paulista region, Brazil, 2019

Clones	Pulp yield (%)	Soluble solids ºBrix (%)	TI
Olivier	62.53 a	8.30 a	5.19 ab
Frutacor	66.75 a	7.60 ab	5.05 a
Cereja	56.25 ab	7.90 ab	4.45 ab
Apodi	67.39 a	6.43 c	4.35 b
Roxinha	66.18 a	7.43 b	4.91 ab
Okinawa	63.99 a	8.43 a	5.40 a
Waldy	47.69 b	6.37 c	3.01 c
Overall mean	**61.54**	**7.50**	**4.62**
F	**6.35****	**21.50****	**12.98****
CV (%)	**9.26**	**4.76**	**9.67**

* Means followed by the same letter in the column do not differ by Tukey's test at the 0.05 significance level.

Figueiredo Neto *et al*. (2014) analyzed three varieties of acerola (Okinawa, Flor Branca and Sertaneja) grown in the Vale do São Francisco region, Brazil, and found that Okinawa presents higher weights for the three maturity stages studied. They also pointed out that the transversal diameters of the Okinawa variety showed increasing values from the green stage to the maturity stage, demonstrating that although the green fruit shows good development in the ripening process, it not only changes its color but also has significant weight gains.

However, the longitudinal diameter of semi-ripe fruit was greater than that of ripe fruit. According to the abovementioned authors, this is due to the fact that this variety is more productive under cold weather conditions, so variations in fruit size occur more frequently among those acerola cultivars because, despite presenting sizes and volumes higher than those of other varieties, such values could be higher according to the favorable weather for the crop. It was also observed that the Okinawa variety, the one with the highest pulp volume, is most susceptible to mechanical damage, even in the green stage.

Adriano *et al*. (2011) evaluated fruit quality in acerola trees cv. Olivier in two maturity stages in the municipality of Junqueirópolis-SP, Brazil. They concluded that semi-ripe fruit had higher total acidity, lower soluble solids content, and lower sugar concentration. However, the fruit showed higher levels of vitamin C, expressed in ascorbic acid. Therefore, to obtain high levels of vitamin C, the fruit should be harvested at a less advanced maturity stage, when still showing an orange color. Their study also showed that cv. Olivier produces fruit with characteristics suitable for both fresh consumption marketing and the industry, presenting a good color and chemical characteristics within the standards for this fruit.

Ferreira *et al*. (2020) studied the physical and chemical characteristics of acerola clones targeted at the produce market and the agribusiness in the Alta Paulista region. The clones evaluated were Olivier (OL), II, VIII, IX, X, Mirandópolis (MD), and Manolo (ML). Those authors identified that in the Alta Paulista region, the acerola clones most suitable for the produce market are Mirandópolis, Manolo, IX and X. The most promising clones for agro-industries are Olivier, II, VIII, IX, X, and Mirandópolis.

Considering the above results, it can be seen that the Olivier cultivar, again, appears as a planting recommendation for the region under study. However, as reported in other studies and observed in the field for more than 10 years, this cultivar is susceptible to nematodes, aphids and leaf-cutting ants (CAVICHIOLI *et al*., 2014), species that frequently occur in the Alta Paulista region. In this context, it can be inferred that such genetic material requires good management in terms of soil fertility to keep plants well nourished and more resistant to pests and diseases.

Conclusion

Given the soil and weather conditions of the Alta Paulista region, Olivier, Apodi and Frutacor are the clones mostly recommended for the agro-industrial market, being the Olivier cultivar the first option among the three and appearing in a greater proportion in the area of the commercial orchard studied.

Regarding the acerola production for fresh consumption, Olivier and Roxinha are the most suitable clones. Olivier stands out for its good yield and its adequate physical and chemical characteristics.

In the manual harvesting of the acerola fruit, the Olivier, Waldy, Apodi and Cereja clones proved to be easier, as opposed to Frutacor, Roxinha and Okinawa.

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