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Phenology and fruit quality of Surinam cherry trees in orchards: training system and seedling growth environment

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Abstract

Surinam cherry (*Eugenia uniflora* L.) is a fruit tree species native to Brazil that produces fruits with potential for food, cosmetic, and pharmaceutical industries. However, there is no technical information for growing Surinam cherry in orchards. The objective of this study was to evaluate the phenology and fruit quality of Surinam cherry trees grown from minicuttings, based on effects of shading during seedling formation and orchard training systems. The experiment was carried out at the Federal University of Technology of Paraná (UTFPR), from 2018 to 2021. A randomized block experimental design with four replications was used, in a 5×3 factorial arrangement, consisted of light intensities during seedling formation and orchard training systems, with varying experimental units according to the analyses. Surinam cherry trees showed differences in the beginning and range of flowering and fruit maturation according to the shading environment used for seedling formation and the orchard training system. The fruit quality of Surinam cherry trees grown from minicuttings was not affected by the analyzed factors.

Keywords: *Eugenia uniflora*, cultural practices, sensory analysis, phenology

Introduction

Surinam cherry (*Eugenia uniflora* L.) is native to Brazil, where it is known as pitangueira; it produces fruits with potential for food, cosmetic, and pharmaceutical industries. This species has raised attention of pharmaceutical industries due to the significant contents of vitamins and antioxidant compounds in its fruits and the antinociceptive, hypothermic, antidiabetic, and antibacterial properties of extracts from its leaves (Silva et al., 2021). Consequently, its market demand has increased, requiring the implementation of commercial orchards with this species to ensure a regular offer of its fruits (Wagner Júnior et al., 2020).

Surinam cherry seedlings are usually grown from seeds due to the ease of handling and challenges related to rhizogenesis when using asexual techniques. However, these seedlings exhibit greater genetic variability caused by gene recombination (Bezerra et al., 2004), which can hinder the management of these plants in orchards and affect the yield and quality of its fruits. The minicutting technique has shown promising results for producing Surinam cherry seedlings (Hossel, 2016), denoting the potential of using this technique successfully in orchards with this species, as long as it presents advantageous characteristics for this purpose. However, there is still no information on the phenology, production, and fruit quality of Surinam cherry trees grown in orchards, using the minicutting technique. This context raises the question whether Surinam cherry seedlings produced under different lighting conditions show the same adaptation under full-sunlight conditions in orchards.

Naturally-grown Surinam cherry trees reach, in general, heights of up to eight meters (Rashmi & Negi, 2022), which is a challenge for commercial orchards due to difficulties in cultural practices and fruit harvesting. Training systems are adopted to overcome this problem

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in fruit growing; the purpose is to define the canopy architecture of plants according to the needs of the fruit grower (Singh et al., 2020).

The adoption of the training system, carried out through pruning in the first years after planting, aims to obtain a uniform and easy-to-manage canopy to achieve a balance between vegetative and productive activity, regular yield, good air circulation, solar radiation penetration, and facilitate phytosanitary treatments (Costa & Fachinello, 2014).

The vase system used in peach, cherry, and plum trees and the central leader system used for apple and pear trees are among commonly used training systems. Both systems could be tested on Surinam cherry tree to elucidate important questions and demonstrate advantages for its growth in orchards, potentially making this neglected species an alternative source of income for fruit growers.

The objective of this study was to evaluate the phenology and the fruit physical and chemical quality of Surinam cherry trees grown from minicuttings, based on effects of shading during seedling formation and orchard training systems.

Materials and Methods

The experiment was carried out from December 2017 to December 2021, in a native fruit orchard and in the Plant Physiology Laboratory of the Federal University of Technology of Paraná (UTFPR), Dois Vizinhos, PR, Brazil. The orchard was in the ecoclimatic region of southwestern Paraná (25°42''S, 53°06''W, and average altitude of 520 meters).

The region's climate is Cfa, according to the Köppen classification, characterized by a subtropical climate, with mean temperature below 18 °C in the coldest month (mesothermal) and above 22 °C in the hottest month, hot summers, infrequent frosts, and rainfall usually concentrated in the summer, without a defined dry season (Alvares et al., 2013). The soil of the orchard was classified as a Typic Hapludox (Nitossolo Vermelho Distroférrico; Bhering & Santos, 2008).

The Surinam cherry seedlings evaluated in the field were grown from asexual propagation, using the minicutting technique (Hossel, 2016). These seedlings were grown under different light intensities for 16 months before planting them in the orchard, as follows: 50%, 35%, and 80% shading, using black shade screens; 35% shading, using a red screen; and full-sunlight conditions (Stefeni, 2018).

The trees were planted on December 8, 2017, with spacing of 4 × 4 m. The trees were irrigated daily during the experiment, using a localized drip irrigation system. The number of waterings and daily water volume applied to the plants varied, as they were dependent on weather conditions. Sulfluramid was applied to control leaf-cutter ants and 1% mineral oil was applied to control mealybugs. Weeds were controlled through harrowing, weeding, and mowing. Regarding plant nutrition, a fertilizer with 45% nitrogen was applied in 2018, 2019, 2020, and 2021, at the beginning of spring. Fifty grams of nitrogen were applied per plant, divided into two applications with a 15-day interval.

The trees were subjected to three different management training systems after established in the field (2018). The training systems used were natural, central leader, and vase. The natural system consists of allowing natural growth, with no management that interfere with the growth habit, architecture, and canopy projection.

The central leader system consists of keeping the main stems of the plants straight using bamboo stakes, which were installed in mid-March 2018. Staking continued until the end of the experiment. In mid-August 2018, lateral shoots were also staked as they were more developed; plastic spreaders were used to project the branches to a 45° angle in relation to the main stem until the they began to lignify. New lateral branches emerged, and when these lateral branches showed signs of lignification, the spreaders were removed and replaced with bamboo stakes fixed to the ground and tied parallel to the lateral branches with plastic tape, maintaining the 45° angle in relation to the main stem. Branches were initially tied with plastic tape, using a binder suitable for this practice. The plastic tapes were replaced with rubber strips when the branches grew and increased in diameter, becoming completely lignified.

The vase system consisted of keeping the main stems of the plants straight, using bamboo stakes and performing a significant pruning to a height of 60 cm from the ground in August 2018, after the growth of the main staked branch. Shoots and lateral branches then appear and four more lateral branches were left. Branches below 25 cm from the ground were removed. Lateral branches were staked and tied with rubber straps at a 60° angle in relation to the main stem, using bamboo stakes fixed vertically to the ground.

The phenology and fruit quality of the plants were evaluated in 2018 based on physical and chemical attributes, following the establishment of the orchard training systems and the beginning of flowering and fruit production. The fruits were randomly harvested at the complete maturity stage, free from mechanical or

natural injuries. The phenology of the plants was assessed in 2018, 2020 and 2021, considering one harvest per year for the variables evaluated.

The phenology was evaluated at the beginning of flowering and full flowering stages for density of flowering buds, beginning and end dates of harvest, and fruit set.

Flowering initiation was evaluated in 2018, 2020, and 2021, considering 5% to 10% of flowers completely open and the end of flowering was evaluated considering 95% of flowers completely open. In 2018, at the final phase of flowering, reproductive structures were aborted. In July 2019, frost events severely damaged the plants, preventing anthesis and consequently affecting the yield. In 2018, there was no fruit set due to frosts after flower petals fell.

Full flowering date was determined by evaluating four randomly chosen branches per plant, where 50% of the floral buds were completely open.

Branch length (cm) was measured and total number of flower buds per branch was counted. Flower bud density was calculated as the number of buds per branch divided by the branch length, in four randomly chosen branches per tree.

The harvest beginning date was recorded when 5% of fruits showed signs of ripeness and the end of the harvest was recorded when 95% of the fruits were ripe. Fruit set was determined by marking four random branches per tree in which the number of flowers was counted and counting the number of fruits generated from these flowers.

Fruits harvested in 2020 and 2021 were individually placed in labeled plastic bags according to the treatments; these bags were then placed in expanded polystyrene boxes containing ice and covered with aluminum foil the fruits. They were then taken to the Plant Physiology Laboratory for analysis.

Fruit yield, color parameters (L*, a* and b*), horizontal and vertical diameters, fresh pulp weight, pulp yield, soluble solids, initial pH, titratable acidity, and vitamin C contents were evaluated.

Fruit production per plant was estimated by multiplying the total number of fruits multiplied by the total fruit fresh weight. Fruit yield per hectare was then calculated by multiplying fruit production per plant (kg plant^{-1}) by the number of trees per hectare; this calculation was based on a planting density is 625 plants ha^{-1} with a spacing of 4×4 m. Fruit color was analyzed by two readings one in each side of the horizontal region of the fruits, using a Minolta Chroma meter CR-400 colorimeter, with a D65 light source and a pointer for emitting a light beam with an aperture of 8 mm. The device was calibrated using a white ceramic plate and the illuminant D65 (z = 93.6; x = 0.3133; y = 0.3195). The fruit epidermis color was evaluated considering the three-dimensional model of chromatic coordinates, as recommended by the CIE (L*, a* and b*). L* represents the lightness of the color (0 indicates black and 100 indicates white). The a* coordinate indicates the color position between green (-a) and red (+a), and the b* coordinate indicates the color position between blue (-b) and yellow (+b) (Sanches et al., 2017).

The horizontal diameter (maximum transverse distance of the fruit) was measured perpendicularly between the two opposite sides of the fruit at its widest point. The vertical diameter (distance from the peduncle to the apex) was evaluated using a digital caliper and the values expressed in millimeters. Pulp fresh weight was evaluated by manually pulping the fruits, separating the pulp from the seeds, and weighing it on an analytical balance.

Pulp yield was obtained by dividing the pulp fresh weight by the total fruit fresh weight and multiplying by 100 to express the values as percentages.

Soluble solids were determined using an RTD-45 digital refractometer in a sample of one or two drops of fruit juice placed on the prism of the device; the results were expressed as °Brix.

The pH of the pulp was determined using a pH-meter with an accuracy of 95%, calibrated according to the manufacturer's recommendations, and buffer solutions of pH = 7.0 and pH = 4.0. Ten mL of juice from a pulp sample was homogenized in 90 mL of distilled water and transferred to a beaker. An electrode was immersed for readings and the pH was recorded after the values in the device stabilized. The electrode was washed in distilled water and dried with a paper towel after each measurement to remove residues from previous samples.

Titratable acidity was determined using a digital buret and a pH-meter, a standardized 0.1 N NaOH solution was titrated to pH 8.1. The results were expressed as grams of equivalent citric acid (EAC) per 100 mL (AOAC, 1996).

Vitamin C contents were determined by titration, using the method described by AOAC (2005), using a 0.02% DFI (2,6-dichlorophenolindophenol) solution (w v^{-1}) until reaching a permanent light pink color. One gram of pulp was diluted in 25 mL of 0.5% oxalic acid (w v^{-1}) and a 5 mL aliquot was used for titration. The results were expressed as mg 100 g^{-1}.

A randomized block experimental design with four replications was used, in a 5×3 factorial arrangement consisting of 5 light intensities during seedling formation

and 3 plant training systems, with 40 fruits and 80 fruits per tree used for replications in physical and chemical analyses, respectively, and one plant per treatment used for phenological evaluations.

The data were subjected to the Lilliefors normality test using the Genes® computer application (Cruz, 2013), which showed the need for transformation for all variables analyzed, which was carried out using the square root of x + 1. The means were then subjected to analysis of variance and Duncan's mean comparison test (a = 0.05) using the Sanest® computer application.

Results and Discussion

Surinam cherry trees in the central leader system began flowering in the first half of July for seedlings grown under 50% black shade screen. In this condition, the flowering range was 25 days (**Figure 1**). However, the longest flowering range (lasting 40 days) was found for trees in the vase system, which were from seedlings grown under a 35% red shade screen (Figure 1).

Flowering was concentrated in September, with a range varying between 14 and 31 days for trees in the natural system (seedlings grown under 50% and 35% red and black shade screens), in the vase system (seedlings grown under 50%, 80%, and 35% black shade screen and full-sunlight), and central leader system (seedlings grown under 80% and 35% black shade screen and full-sunlight) (Figure 1).

The flowering of Surinam cherry trees can occur in August and last until November (Lorenzi et al., 2015). This information confirms the results shown in **Figures 1**, **2**, and **3**. However, according to Pelacani et al. (2000) and Franzon et al. (2008), Surinam cherry tree flowering can occur sparsely throughout the year, and is affected by soil and climate conditions and management of trees.

Environmental factors define biological events and are directly connected to tree phenology (Semensato et al., 2020). According to Rathcke & Lacey (1985), climatic, edaphic, and biotic factors, mainly rainfall fluctuations, influence the flowering and fruiting periods of tropical plants. This information is consistent with the precipitation conditions found in the present study (Figure 6), which showed rainfall fluctuations throughout the year in 2019, 2020, and 2021, and may have affected the phenology of Surinam cherry trees.

The flowering range varied between 15 and 25 days for trees from seedlings grown under 35% shade (black and red screens) in the natural system, 80% shade and full-sunlight in the vase system, and varying shade levels (50% and 80% black screens and 35% red screen) and full-sunlight in the central leader (Figure 1).

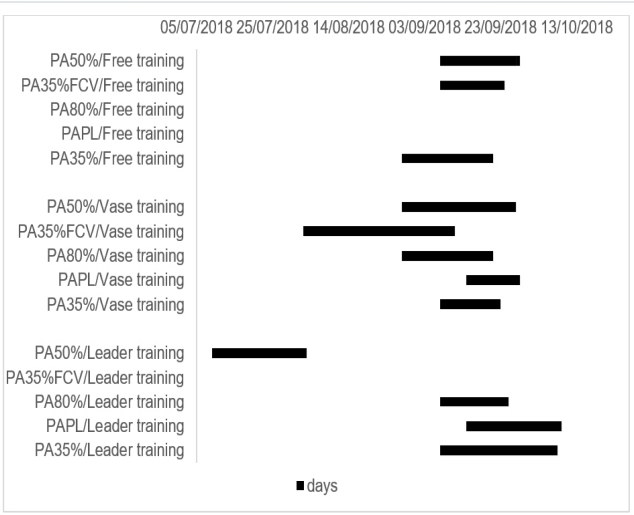

Figure 1 - Flowering range of Surinam cherry trees in 2018 (*Eugenia uniflora* L.) as a function of orchard training systems (natural, vase, and central leader) and shading environment for seedling formation [50% (PS50%), 80% (PS80%), and 35% (PS35%) red black screen; 35% red screen (PS35%FCV); and full-sunlight (PSPL)].

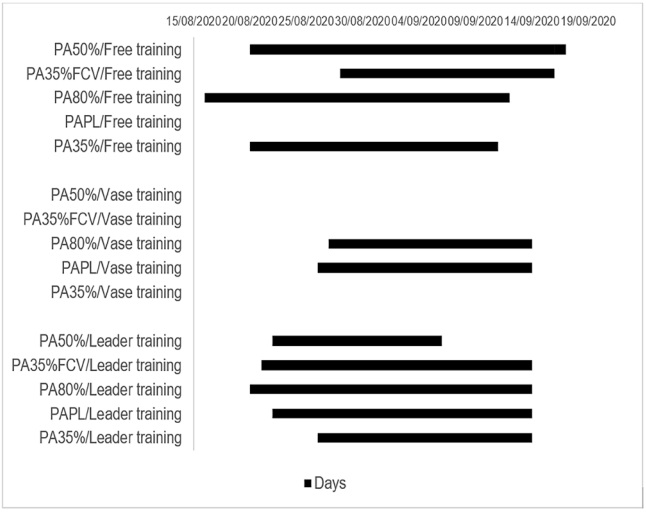

Figure 2 - Flowering range of Surinam cherry trees in 2020 (*Eugenia uniflora* L.) as a function of orchard training systems (natural, vase, and central leader) and shading environment for seedling formation [50% (PS50%), 80% (PS80%), and 35% (PS35%) black screen; 35% red screen (PS35%FCV); and full-sunlight (PSPL)].

Surinam cherry tree flowering was more concentrated in 2020 compared to 2018 (Figure 1) and 2021 (Figure 3). Flowering started on August 16, 2020, in plants from seedlings grown under 80% shade in the natural system. Similarly, the longest flowering ranges were found for trees from seedlings grown in environments with 50% and 80% shading in the natural system, with a flowering range of 27 days (Figure 2).

In 2021 (Figure 3), flowering began considerably early for trees in the natural system from seedlings grown under varying shade levels (50% black screen, 35% red and black screen, 80% black screen, and full-sunlight),

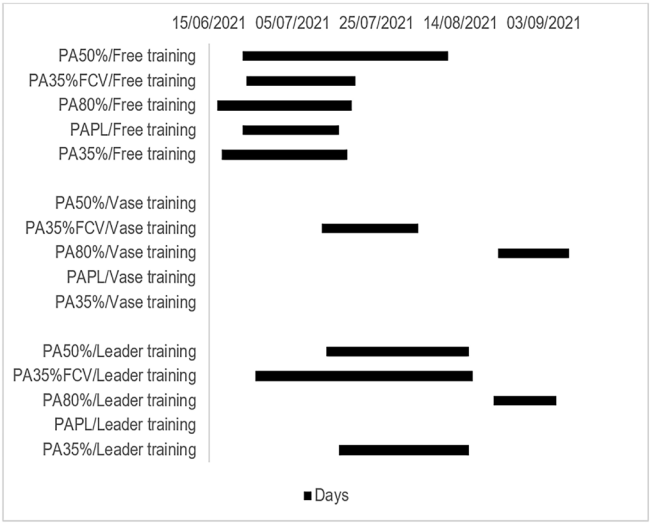

Figure 3 - Flowering range of Surinam cherry trees (*Eugenia uniflora* L.) in 2021 as a function of orchard training systems (natural, vase, and central leader) and shading at seedling formation [50% (PS50%), 80% (PS80%), and 35% (PS35%) black screen, 35% red screen (PS35%FCV), and full-sunlight (PSPL)].

staring on June 17, 2021 for those from seedlings formed under 80% shade. The longest flowering range was found for trees grown from seedlings formed under 35% red shade screen in the central leader system, lasting 52 days. All other trees, regardless of training system or light intensity during seedling formation, exhibited flowering ranges between 15 and 48 days (Figure 3).

In the Center-West region of Brazil, Surinam cherry tree flowering was recorded at the end of the dry season and beginning of the rainy season, between August and October, with a flowering range of intermediate duration (Newstron et al., 1994; Aoki et al., 2018). These results differ from those found in the present study, despite the occurrence of dry periods (Figure 6).

Fruit harvesting in 2020 was concentrated from September 21, 2020 to the beginning of the second half of October for the following treatment groups: all trees in the natural system; those in the vase system from seedlings grown under 80% shade and full-sunlight; and those in the central leader system from seedlings grown under 35% red screen, 80% black screen, and full-sunlight. However, the longest harvest range was 36 days, found for plants in the vase system grown from seedling formed under 80% shade. The lowest harvest range (20 days) was found for plants in the central leader system grown from seedlings formed under 35% black shade screen (**Figure 4**).

In 2021, fruit harvest began on September 11th for trees grown in the in the natural system from seedlings formed under 80% and 35% shade and full-sunlight. These conditions also resulted in the longest harvest ranges, lasting 44, 33, and 42 days, respectively.

The longest harvest range in the vase system was

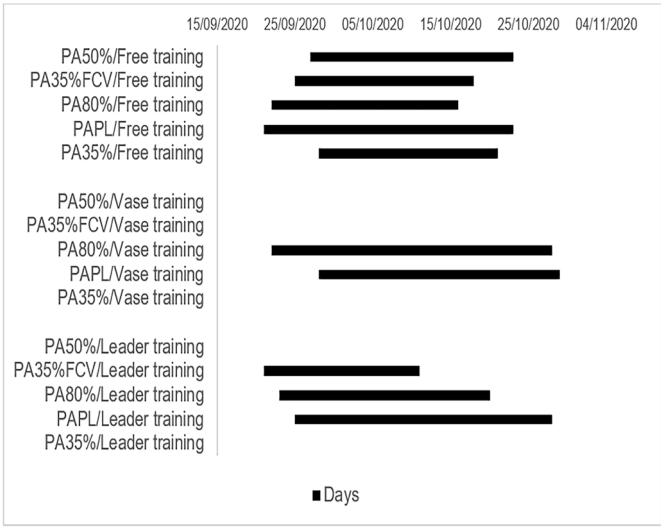

Figure 4 - Harvest range of Surinam cherry trees (*Eugenia uniflora* L.) in 2020, according to the orchard training system (natural, vase, and central leader) and shading environment for seedling formation [50% (PS50 %), 80% (PS80%), and 35% (PS35%) black screen; 35% red screen (PS35%FCV), and full-

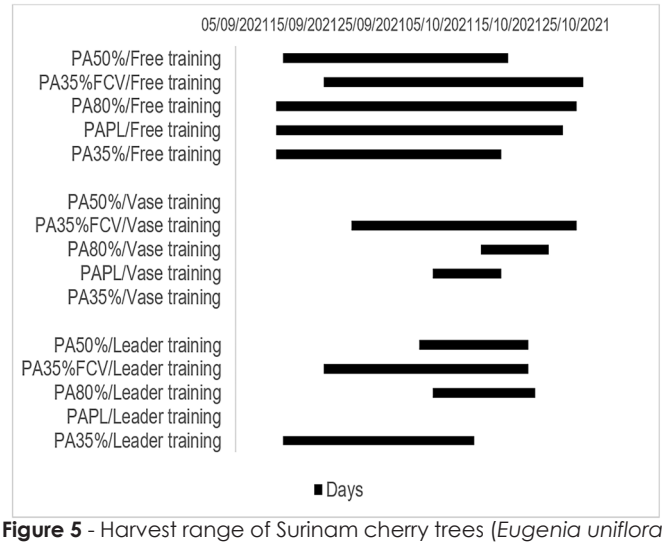

Figure 5 - Harvest range of Surinam cherry trees (*Eugenia uniflora* L.) in 2021 as a function of orchard training systems (natural, vase, and central leader) shading environment for seedling formation [50% (PS50%), 80% (PS80%), and 35% (PS35%) black screen; 35% red screen (PS35%FCV), and full-sunlight (PSPL)].

33 days, found for trees grown from seedlings formed under 35% red screen shade. The harvest range varied from 10 days (plants from seedlings grown in full-sunlight conditions in the vase system) to 44 days (plants from seedlings grown under 80% shade) (**Figure 5**).

The different harvest ranges among and within the years are connected to meteorological conditions (**Figure 6**), as they affect the physiology of the Surinam cherry trees, resulting in a staggered maturation of fruits. A greater harvest range is an advantageous condition to fruit growers, as it allows a greater fruit supply to the market, covering different periods, which may coincide with times of greater demand and little supply, adding value to the fruit.

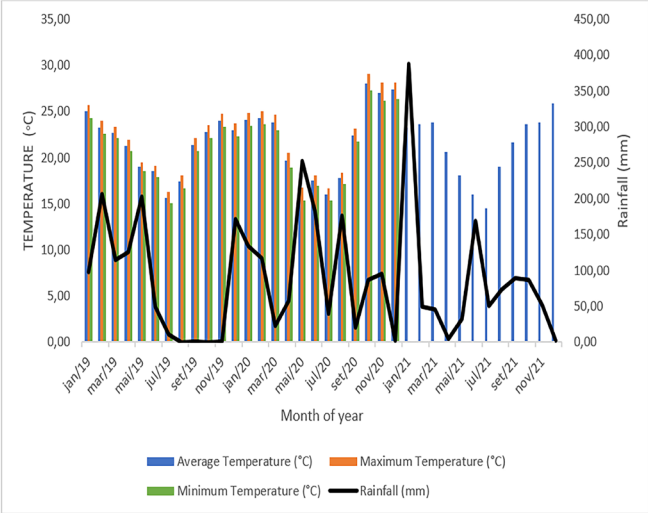

Figure 6 - Monthly mean, maximum, and minimum temperatures (°C) and monthly accumulated rainfall depth (mm) between January 01, 2018 to December 31, 2021 in the area close to the Surinam cherry tree orchard.

The interaction between the factors (light intensities for seedling formation and training systems) and the individual factors had no significant effects on flower bud density per centimeter of branch, fruit set, and fruit density per centimeter of branch in 2020 and 2021, and on fruit yield in 2020.

Fruit yield in 2020 and 2021 and production per plant in 2021 were significantly affected by the plant training systems **(Table 1**).

In 2021, the highest fruit production was found for Surinam cherry trees grown in the natural system, with a mean of 11.86 kg, followed by those in the vase system (1.55 kg) and in the central leader system (0.78 kg). Trees in the natural system also had higher fruit yield in 2020 and 2021 (Table 1).

These results may be attributed to the lack of intervention in the natural system, allowing branches to grow freely, leading to greater vigor and faster crown formation, resulting in more favorable conditions for fruit production.

Franzon et al. (2004) evaluated Surinam cherry trees and found yields between 15 kg and 23 kg plant^{-1} in a single harvest. Contrastingly, Lira Júnior et al. (2010) found mean yields between 6.71 kg and 26.12 kg plant^{-1}, with a mean of 19.41 kg plant^{-1}.

These variations may be related to the analyzed genotype, training system, and specially tree age, as Surinam cherry tree production tends to increase over the years until reaching stability around six years (Lira Júnior et al., 2007).

Therefore, further experimental studies are essential, as Surinam cherry trees in the present study have not yet reached their maximum production potential. Additionally, these plants originated from minicutting propagation; thus, these results may differ from those described in the literature.

Regarding the variables related to fruit quality attributes (physical and chemical), only for the b* color variable in 2020 was significantly affected by the training system factor (**Table 2**). The individual factors and the interaction between them had no significant effect on the other variables in the analyzed periods.

The lack of significant effects on fruit quality-related variables was probably because the fruits evaluated were from the same asexually propagated trees; these trees have practically no genetic variability, differing from trees grown from seeds.

Standardized fruits with good visual appearance attract consumers, which makes the maintenance of standards of fruit quality parameters essential for marketing. Therefore, trees originated from asexual propagation techniques are commonly used in commercial orchards.

The means found for the fruit variables L* (lightness), a* (red to green), horizontal and vertical diameters, fruit fresh weight, pulp yield, soluble solids, pH, total acidity, and vitamin C were, respectively: 26.40; 26.59; 18.27 mm; 15.73 mm; 5.24 g; 71.10%; 12.8 °Brix; 6.06; 6.36 g EAC; 5.32 mg 100 g^{-1} in 2020; and 24.38; 25.97; 18.47 mm; 14.29 mm; 2.40 g; 79.90%; 9.98 °Brix; 2.97; 17.05 g EAC; 4.25 mg 100 g^{-1} in 2021, respectively.

In 2020, the mean found for the fruit color parameter b* was higher in plants grown in the natural and central leader systems (Table 2). The b* parameter is represented by chromaticity, corresponding to the blue to yellow intensity, which can vary from -50 (totally blue)

Table 1 - Fruit yield (FY; kg ha^{-1}) in 2020 and 2021 and production per plant (PP; kg plant^{-1}) in 2021 for Surinam cherry trees grown in three different training systems.

Training system	FY 2020	PP 2021	FY 2021
Natural	275.89a**	11.86a*	5342.36a*
Vase	11.04b	1.55b	428.61b
Central Leader	3.61b	0.78b	205.57b
Coefficient of variation (%)	19.94	13.21	21.86

Means followed by the same letter in the columns are not statistically different from each other by the Duncan's test (α = 0.05).

Table 2 - Color parameter b* of Surinam Cherry (*Eugenia uniflora* L.) fruits in 2020, from trees propagated asexually and grown in different training systems in an orchard.

Training system	Color b*
Natural	25.51 a*
Vase	20.68 b
Central Leader	21.46 ab
Coefficient of variation (%)	8.60

Means followed by the same letter in the columns are not statistically different from each other by the Duncan's test (α = 0.05).

to +70 (totally yellow) (Harder et al., 2007).

The color of the fruit contributes to its appearance, increasing consumer acceptability (Jorge et al., 2021). Fruit color is influenced by the presence of pigments, which are secondary metabolites that can be formed due to stress conditions, resulting in a more bluish or yellowish coloration. These metabolites are characterized by their antioxidant potential and relevant function in preventing diseases and maintaining human health (Rao & Rao, 2007).

Conclusion

Surinam cherry trees showed differences in the beginning and range of flowering and in fruit maturation according to the shading environment used for seedling formation and orchard training system.

The shading environments for seedling formation and orchard training systems evaluated had no significant effect on the quality fruit-related variables analyzed in Surinam cherry of trees grown from minicuttings, which may be associated with the existing genetic uniformity.

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