

Article

Grafting with *Passiflora* spp. as a Productive Strategy in the Cultivation of *Passiflora edulis* with Saline Water

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Abstract

Salinity causes morphophysiological changes that compromise the growth and production of cultivated species, such as *Passiflora edulis*. However, wild species better tolerate environmental adversities. Therefore, we evaluated the performance of *P. edulis* scion (Guinezinho, BSR YG1, BRS SC1) grafted on *Passiflora* rootstocks (*P. cincinnata*, *P. foetida*, and *P. edulis*), regarding the electrical conductivity of irrigation water (0.5 and 3.0 dS m⁻¹), and it was hypothesized that rootstocks would mitigate the effects of salinity and that there is a difference between non-grafted cultivars. Grafted plants reached the trellis stage sooner, and the use of *P. foetida* rootstocks reduced the time to prune the stem. The highest productivity was obtained with the YG1 cultivar grafted onto *P. foetida*, under irrigation with water salinity, reaching 8073.96 kg ha⁻¹ and exceeding by up to 139.19% the other grafting and electrical conductivity of the irrigation water. The grafting technique proved effective in mitigating the effects of salinity, particularly the combination between *P. foetida* and YG1 cultivar *P. edulis*, which showed compatibility and superior agronomic performance under saline stress conditions. These results indicate a promising strategy for the sustainability of yellow passion fruit cultivation in semi-arid regions, contributing to the maintenance of productivity, even in environments with restricted water quality resources.

Keywords: *Passiflora foetida*; *Passiflora cincinnata*; rootstock; salt stress; scion compatibility; cytokinin; irrigation salinity; sour passion fruit



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1. Introduction

In semi-arid regions, the spatio-temporal irregularity of rainfall and the excess of salt in the water available for irrigation compromise agricultural activity [1]. Given the scenario of climate change, it is predicted that semi-arid regions worldwide will experience higher

temperatures and lower precipitation, with greater impacts on water supply and patterns of soluble salt concentrations [2]. Saline stress affects crop productivity, and its negative impact on global food security may increase due to current climate trends [3].

In the Brazilian semi-arid region, the yellow passion fruit is a crop with significant economic and social importance, offering the possibility of rapid economic return and income distribution throughout the year. The northeast region is responsible for 72.78% of production; however, with a productivity of 15.28 t ha^{-1} [4], this value is lower than the crop's productive potential, which can exceed 50 t ha^{-1} [5] in a harvest year. Among the factors that compromise productivity are the high salt content in water sources [1], which are often used for crop irrigation. When greater than 3.0 dS m^{-1} [6], it promotes physiological and nutritional imbalances [7,8], inhibiting growth and development [9], and reducing fruit production in *P. edulis* [1,10].

Osmotic and ionic stress caused in plants by salinity triggers the overproduction of reactive oxygen species (ROS), which cause oxidative damage to cellular organelles and membrane components. To mitigate the effects of excess salt in irrigation water, plants activate tolerance mechanisms, such as the induction of the antioxidant defense system to protect the plant from oxidative damage induced by excess soluble salts, deactivating reactive oxygen species and maintaining the balance of generation of these species [11–13]. Plants can restrict the absorption and transport of toxic ions (Na^+ and Cl^-) [14], accumulate and excrete salts through the roots [15,16], and modulate the hormonal state to protect plants when exposed to saline stress [17,18].

The tolerance of crops to salinity can vary between species and genotypes [10]. This adaptive characteristic is often present in wild relatives of cultivated species [3]. Among the large number of wild *Passiflora* species with promising potential for rootstock production, with economically viable yield and quality, *P. cincinnata*, *P. foetida*, and *P. gibertii* stand out [19]. Under non-saline conditions, grafting *P. edulis* onto wild passiflora often reduces growth and productivity [20–22]. However, under saline stress, the tolerance characteristics of the rootstock can provide advantages [13,14]. This relationship between vigor and stress tolerance is still poorly understood. The use of wild passion fruit species as rootstocks can likely add desirable mechanisms to the crop. For example, the salinity tolerance observed in *P. foetida* rootstocks allows plants to be produced with water with an electrical conductivity of 4.0 dS m^{-1} [23], associated with increased tolerance to saline stress through the reduction in reactive oxygen species (ROS) accumulation, especially hydrogen peroxide, as a result of enhanced activity of antioxidant enzymes, including catalase [13].

Grafting can alter growth patterns in both the scion and the rootstock [24] due to the mutual influence between them. Thus, compatibility between grafted species varies according to the specific rootstock–scion combination [13]. Each rootstock–scion relationship is unique, especially in genetically distinct combinations; therefore, there is no universal physiological or morphological mechanism or response applicable to all combinations [25].

Given the worsening effects of climate change, which reduce the availability and quality of water for irrigation, especially in semi-arid regions, and considering the significant cultivation of yellow passion fruit in these areas, as well as the sensitivity of this crop to saline water, the development of resilient agricultural strategies becomes urgent. In this context, the use of *Passiflora* species as rootstocks emerges as a promising alternative, since the interactions between scion and rootstock can significantly influence the growth, development, and productivity of plants under adverse environmental conditions. Thus, we hypothesize that certain combinations between *P. edulis* cultivars, as scion, and passiflora species used as rootstock exhibit greater agronomic compatibility, being able to tolerate the negative effects of salinity and, consequently, improve the performance of yellow passion fruit (*P. edulis*) under saline stress conditions.

This study evaluated the performance of *P. edulis* (Guinezinho, BRS Yellow Giant, and BRS Sun of Cerrado cultivars), both ungrafted and as scions onto wild *Passiflora* species (*P. cincinnata*, *P. foetida*, and *P. edulis*) under saline irrigation (0.5 and 3.0 dS m⁻¹), assessing phenophases, growth, and productive aspects.

2. Materials and Methods

2.1. Description of the Experimental Area and Soil Attributes

The experiment was conducted between October 2022 and December 2023 at the Angico Site (8°07'16" south latitude, 37°00'05" longitude west of Greenwich and 588 m altitude), municipality of São Sebastião do Umbuzeiro in Paraíba. The municipality is in the BSh climate zone, according to the Köppen classification, which means it has a semi-arid climate [26]. Meteorological data during the field phase were recorded by a professional meteorological station, model FT-0310 (NicetyMeter®, Shenzhen, China), as shown in Figure 1.

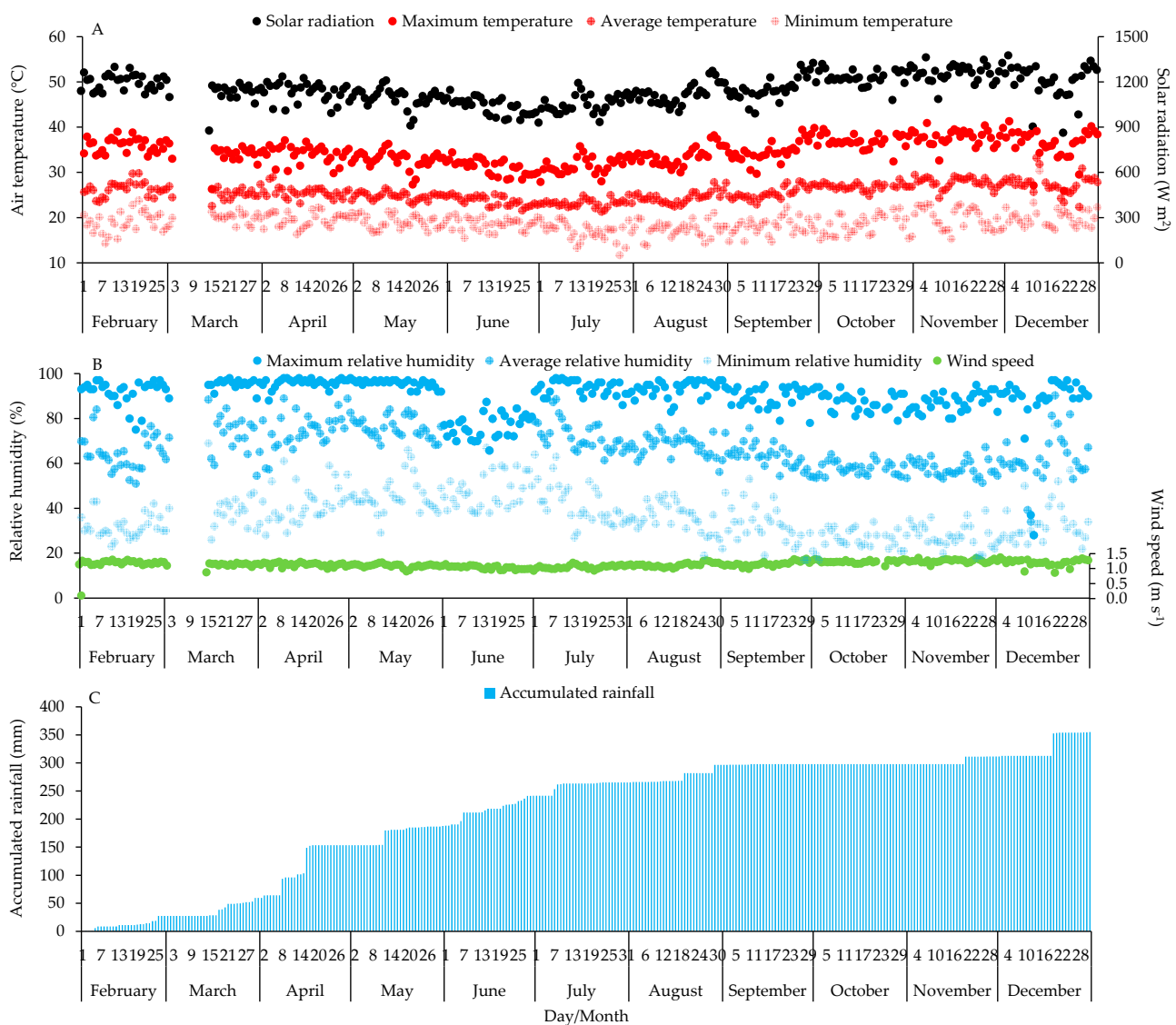


Figure 1. Daily meteorological data for maximum, minimum, and average solar radiation and maximum, minimum, and average air temperature (A); maximum, minimum, and average relative air humidity and maximum wind speed (B); and accumulated rainfall (C).

The soil in the experimental area was classified as Entisols Torriorthents [27], and two composite samples, from the 0–20 cm and 20–40 cm layers of the profile, were collected and analyzed for chemical (fertility and salinity) and physical attributes [28] (Table 1).

Table 1. Chemical (fertility and salinity) and physical attributes of the 0–20 and 20–40 cm depth layers of the profile of Entisols Torriorthents before the experiment was set up.

Chemical attributes—Fertility ¹													
Layer	pH	P	K ⁺	Na ⁺	Ca ²⁺	Mg ²⁺	SB	H ⁺ + Al ³⁺	Al ³⁺	CEC	V	ESP	OM
- cm -	---	mg dm ⁻³	cmol _c dm ⁻³								----- % -----		g kg ⁻¹
0–20	5.8	3.72	0.29	0.10	5.21	1.38	6.98	2.43	0.05	9.41	74.2	1.1	10.66
20–40	6.2	2.54	0.12	0.18	6.46	2.17	8.93	2.19	0.09	11.12	80.3	1.6	5.87
Chemical attributes—Salinity in the saturation extract ²													
Layer	pH	ECse	K ⁺	Na ⁺	Ca ²⁺	Mg ²⁺	Cl [–]	HCO ₃ [–]	CO ₃ ²	SO ₄ ^{2–}	SAR		
- cm -	---	dS m ⁻¹	mmol _c L ⁻¹								mmol _c L ⁻¹		
0–20	6.9	0.69	0.25	1.17	4.25	3.42	4.90	4.80	0.00	0.44	0.60		
20–40	7.11	0.36	0.08	1.26	1.25	1.92	4.90	4.80	0.00	0.52	1.00		
Physical attributes ³													
Layer	Sand	Silt	Clay	WDC	Df	Ds	Dp	TP	Moisture (MPa)			Textural class	
									0.010	0.030	1.500		
- cm -	g kg ⁻¹				%	- kg dm ⁻³ -		m ³ m ⁻³	g kg ⁻¹				
0–20	682	186	132	51	61.4	1.38	2.66	0.48	143	132	56	Sandy Loam	
20–40	676	216	108	51	52.8	1.34	2.70	0.50	147	123	61	Sandy Loam	

¹ pH (potential of hydrogen) in water; P (phosphorus), K⁺ (potassium) and Na²⁺ (sodium) with extractor Mehlich 1; Ca²⁺ (calcium), Mg²⁺ (magnesium), and Al³⁺ (aluminum) with KCl 1 M; H⁺ + Al³⁺ (hydrogen plus aluminum) with extractor calcium acetate 0.5 M at pH 7.0; SB (sum of bases) = K⁺ + Na⁺ + Ca²⁺ + Mg²⁺; CEC (cation exchange capacity) = SB + H⁺ + Al³⁺; V (base saturation) = (SB/CEC) × 100; ESP (exchangeable sodium percentage) = (Na⁺/CEC) × 100; OM (organic matter) = organic carbon × 1.724, Walkley–Black method; ² ECse (electrical conductivity of the soil saturation extract at 25 °C); SO₄²⁻ (sulfate); CO₃²⁻ (carbonate); HCO₃²⁻ (bicarbonate); Cl⁻ (chloride); SAR (sodium adsorption ratio) = Na⁺ / [0.5(Ca²⁺ + Mg²⁺)]^{0.5}; ³ particle size distribution using the densimeter method, dispersant NaOH 1 M; WDC (water-dispersible clay); Df (degree of flocculation) = ((total clay – WDC)/total clay) × 100; Ds (density of soil); Dp (density of particle); TP (total porosity) = (Dp – Ds)/Dp.

2.2. Treatments and Experimental Design

The treatments were organized into split plots, in a scheme 2 × [(3 × 3) + 3], with the main plot being the electrical conductivity of the irrigation water (0.5 and 3.0 dS m⁻¹) and the subplots resulting from the combination of three species as rootstock (*P. cincinnata*, *P. foetida*, and *P. edulis* cultivar Guinezinho) and three cultivars of *P. edulis* Sims as scion (Guinezinho and the hybrids, BRS Yellow Giant F1—YG1, and BRS Sun of Cerrado F1—SC1), plus the three ungrafted *P. edulis* cultivars, totaling 24 treatments. The treatments were distributed in four randomized blocks, and each experimental unit contained four plants.

2.3. Conducting the Experiment

2.3.1. Seedling Production

Seeds of *P. cincinnata* and the commercial hybrids *P. edulis* BRS Yellow Giant F1 (YG1) and BRS Sun of Cerrado F1 were obtained from a company accredited for the commercialization of passion fruit seeds. Seeds of wild passion fruit (*P. foetida*) were extracted from fruits collected from plants located in the Seridó region, Rio Grande do Norte State, Brazil. Seeds of the *P. edulis* cultivar Guinezinho were obtained from fruits collected from a cultivation located in the same region.

For sowing, 128-cell trays filled with commercial substrate were used (Basaplant®, São Paulo, SP, Brazil), composed of pine bark, vermiculite, sand, limestone rock, and

phosphate rock, with an electrical conductivity of 0.5 dS m^{-1} and a water-holding capacity of 150%. One seed was sown per cell, and the trays were distributed under shade cloth (50%). Due to differences in emergence and growth speed [19], *P. cincinnata* was sown first, and after 30 days, *P. foetida* was sown—since these seeds were previously soaked in distilled water for 24 h, with the water being changed every 12 h—and after seven more days, *P. edulis* was sown. Thirty-five days after sowing *P. edulis*, the seedlings were transplanted into polyethylene bags with a capacity of 2 dm^3 and filled with a mixture of soil from the 0–20 cm layer of Entisols torriorthents and cured bovine manure in a ratio of 3:1 (v/v), which was characterized in terms of chemical (fertility and salinity) and physical attributes [28] (Table 2).

Table 2. Chemical (fertility and salinity) and physical attributes of the substrate used for seedling production.

Chemical attributes—Fertility ¹												
pH	P	K ⁺	Na ⁺	Ca ²⁺	Mg ²⁺	SB	H ⁺ + Al ³⁺	Al ³⁺	CEC	V	ESP	OM
---	mg dm ⁻³	----- cmol _c dm ⁻³ -----						----- % -----			g kg ⁻¹	
8.2	171.04	3.55	1.08	7.38	2.01	14.02	0.00	0.00	14.02	100.0	7.7	25.81
Chemical attributes—Salinity in the saturation extract ²												
pH	ECse	K ⁺	Na ⁺	Ca ²⁺	Mg ²⁺	Cl ⁻		HCO ₃ ⁻	CO ₃ ²⁻	SO ₄ ²⁻	SAR	
---	dS m ⁻¹	----- mmol _c L ⁻¹ -----								mmol _c L ⁻¹		
8.6	9.24	27.09	16.00	36.50	23.44	72.40		29.80	0.00	13.01	2.92	
Physical attributes ³												
Sand	Silt	Clay	WDC	Df	Ds	Dp	TP	Moisture (MPa)			Textural class	
								0.010	0.030	1.500		
----- g kg ⁻¹ -----				%	- kg dm ⁻³ -	m ³ m ⁻³		----- g kg ⁻¹ -----				
686	236	78	51	34.6	1.26	2.60	0.53	178	149	87	Sandy Loam	

¹ pH (potential of hydrogen) in water; P (phosphorus), K⁺ (potassium), and Na²⁺ (sodium) with extractor Mehlich 1; Ca²⁺ (calcium), Mg²⁺ (magnesium), and Al³⁺ (aluminum) with KCl 1 M; H⁺ + Al³⁺ (hydrogen plus aluminum) with extractor calcium acetate 0.5 M at pH 7.0; SB (sum of bases) = K⁺ + Na⁺ + Ca²⁺ + Mg²⁺; CEC (cation exchange capacity) = SB + H⁺ + Al³⁺; V (base saturation) = (SB/CEC) × 100; ESP (exchangeable sodium percentage) = (Na⁺/CEC) × 100; OM (organic matter) = organic carbon × 1.724, Walkley–Black method; ² ECse (electrical conductivity of the soil saturation extract at 25 °C); SO₄²⁻ (sulfate); CO₃²⁻ (carbonate); HCO₃²⁻ (bicarbonate); Cl⁻ (chloride); SAR (sodium adsorption ratio) = Na⁺ / [0.5(Ca²⁺ + Mg²⁺)]^{0.5}; ³ particle size distribution using the densimeter method, dispersant NaOH 1 M; WDC (water-dispersible clay); Df (degree of flocculation) = ((total clay – WDC)/total clay) × 100; Ds (density of soil); Dp (density of particle); TP (total porosity) = (Dp – Ds)/Dp.

The scions were performed at 77 days after the transplanting of *P. cincinnata*, after 50 days for *P. foetida*, and after 43 days for *P. edulis*, all on the same day, with transplanting to the field taking place 35 days after grafting. The grafting method [29,30] was a full cleft scion, with the seedlings kept under shade cloth (75%) and in a humid chamber for the first seven days, followed by 14 more days under shade cloth (50%) and a further 14 more days in full sun. The trays and seedlings were irrigated twice a day with good-quality, non-saline water from a reservoir, with irrigation reduced in the first seven days after grafting. The stages of seedling production are outlined in Figure 2.

2.3.2. Organization of the Experimental Area and Plant Management

The plant support system was of the espalier type, with the stakes spaced 3.0 m apart along the line and 2.5 m between lines, with smooth wire No. 12 installed on top of the stakes at 2.0 m from the ground. Prior to transplanting, planting holes were dug with an edge of 0.40 m being filled with a mixture of the 0.0–0.2 m layer of Entisols torriorthents from the experimental area mixed with 20 dm³ of properly mineralized cattle manure and initial mineral fertilization [31].



Figure 2. Stages of seedling production: (1) sowing, (2) transplanting, (3) grafting, (4) humid chamber, (5) changes after grafting, and (6) acclimatization process of seedlings under full sun for subsequent transplanting.

The transplanting of the seedlings to the field was carried out 35 days after grafting, with one seedling per planting hole and a population density of 1333 plants per hectare. The seedlings were trained on a single stem to the support system using sisal twine and, after hitting the support wire, this main stem was pruned, and a secondary branch was trained over the wire on each side of the cultivation rows, which were pruned after each had grown to 1.5 m. The tertiary branches, which form the production curtain, were pruned to remain 0.5 m from the ground, and production was only permitted from these. These stages of organizing and managing the experimental area are shown in Figure 3.

2.3.3. Fertilization Management

Fertilization management was based on soil analysis of the 0–20 cm layer (Table 1) and recommendations for yellow passion fruit cultivation [31]. At planting, each hole received 20 dm³ of cured cattle manure (33.3 m³ ha^{−1}) [32], 50 g of FTE-BR 12, and 72 g of P₂O₅ as single superphosphate (Table 3). During the formation phase, nitrogen was applied around each plant at 30 days after transplanting (6 g N) and subsequently at 30-day intervals for up to 180 days (12 g N per application), using urea. Potassium was applied at 60 days (6 g K₂O) and from 90 to 180 days after transplanting (7.8 g K₂O per application), using potassium chloride and potassium sulfate as sources. In the production phase, at 240 and 300 days after transplanting, 14.4 g N, 18 g K₂O, and 18 g P₂O₅ per plant were applied using urea, potassium chloride and sulfate, and mono-ammonium phosphate. Foliar fertilization was performed every 60 days using Niphokam® 10-08-08 (Fênix Agro-Pecus Industrial Ltda., Tietê, SP, Brasil) at a dose of 2 mL L^{−1}.

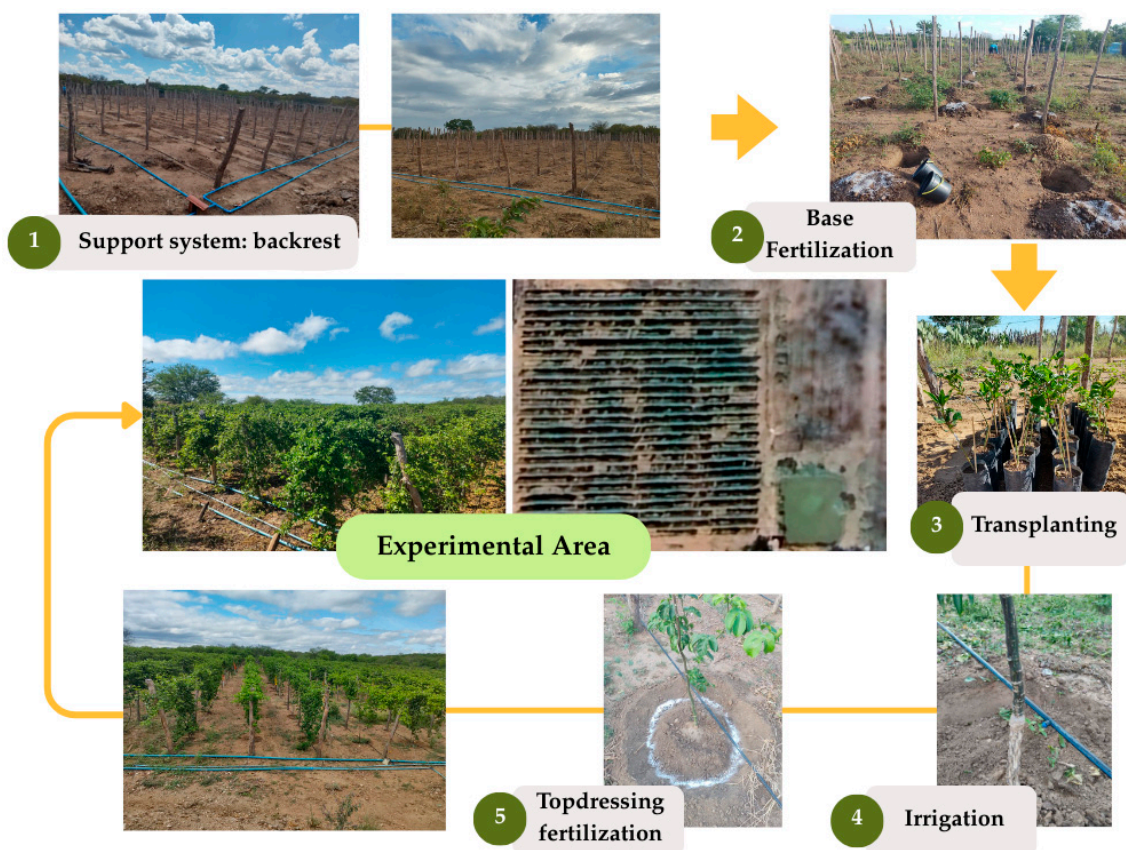


Figure 3. Stages of organizing and managing the experimental area: (1) support system: trellis, (2) base fertilization, (3) transplant, (4) irrigation, and (5) topdressing fertilization.

Table 3. Composition of the bovine manure used for preparing the planting holes and the substrate for seedling production.

N	P	K	Ca	Mg	Na	S	Cu	Fe	Mn	Zn	B	Cl
----- g kg ⁻¹ -----						----- mg kg ⁻¹ -----						
13.34	5.96	14.00	27.80	8.30	0.64	3.00	12.0	70.0	58.0	35.0	44.7	22.5
pH	EC	CEC	Organic Carbon (OC)			Organic Matter (OM)			C/N	Moisture		
---	dS m ⁻¹	----- g kg ⁻¹ -----						---	%			
8.26	11.30	54.74	178.74			308.14			13.40	15.90		

N (nitrogen), sulfuric digestion, and Kjeldahl method; P (phosphorus), K (potassium), Ca (calcium), Mg (magnesium), S (sulfur), Cu (copper), Fe (iron), Mn (manganese), Zn (zinc) e Na (sodium), and nitric-perchloric digestion; B (boron), dry digestion; Cl (chloride), aqueous extraction; pH (potential of hydrogen); EC (electrical conductivity); CEC (cation exchange capacity) = K + Ca + Mg + Na; CO, Walkley–Black method.

2.3.4. Irrigation Management

The irrigation system was of the localized type, with two drippers per plant, spaced 0.1 m from the plant stem, and with hydraulic head loss control, an individual flow rate of 10 L h⁻¹, working at a service pressure of 0.15 MPa, and an irrigation frequency of up to three times a week. The water used for irrigation came from the Santo Antônio state dam and a tubular well on the property, which were chemically analyzed [28] (Table 4). Irrigation water with an electrical conductivity of 3.0 dS m⁻¹ was prepared in plastic tanks (5 m³ capacity) by mixing groundwater from a tubular well, which presented higher salinity, with surface water from a reservoir, adjusting the mixture until the target conductivity was achieved.

Table 4. Chemical composition of water used for irrigation.

Sample	pH	EC dS m ⁻¹	K ⁺	Na ⁺	Ca ²⁺	Mg ²⁺	Cl ⁻	HCO ₃ ⁻	CO ₃ ²⁻	SO ₄ ²⁻	RAS - % -	Classification
	---		----- mmol _c L ⁻¹ -----									-----
Dam	7.3	0.50	0.29	1.02	1.70	1.49	2.40	7.40	0.00	0.24	0.81	C2S1
Tubular well	7.1	4.42	0.43	29.93	13.25	22.63	47.40	19.90	0.00	0.49	5.65	C4S2

Dam (a surface water reservoir); tubular well (a drilled perforation in the ground used to extract groundwater); pH (potential of hydrogen); EC (electrical conductivity); RAS (sodium adsorption ratio) = $\text{Na}^+ / [0.5(\text{Ca}^{2+} + \text{Mg}^{2+})]^{0.5}$; C2S1 = Medium risk of salinization and low risk of soil sodification by water; C4S2 = High risk of salinization and medium risk of sodification of the soil by water.

Irrigation management was based on crop evapotranspiration (ET_c), calculated by the product of reference evapotranspiration (ET_o), the crop coefficient in each phenophase (k_c) of the crop, and the area reduction coefficient (k_r) (ET_c = ET_o × k_c × k_r). The reference evapotranspiration was obtained using the Penman–Monteith, FAO standard method [33]. The crop coefficients were 0.64 during apical growth, 0.98 during the growth of lateral and productive branches, and 1.17 during flowering and fruiting [34]. The reduction coefficient considered values of 0.49 up to 98 days after transplanting, and 0.83 for the remainder of the cycle, considering the shading of 25 and 50%, respectively [35]. Treatments with saline water were initiated 30 days after transplanting the seedlings, and 25% was added to the irrigation volume to promote the leaching of excess salts from the root environment of the plants [36].

2.3.5. Phytosanitary Management and Cultural Practices

The cultural practices for weed, pest, and disease control were carried out according to the crop's needs and the recommendations for passion fruit cultivation [37]. The weeding was done with a hand hoe, keeping both the planting holes and the streets clean. For phytosanitary control, Decis® 25EC (Bayer S.A., São Paulo, SP, Brazil), Tenaz® 250 SC (Sumitomo Chemical Brasil Indústria Química S.A., Maracanaú, CE, Brazil), Thiobel® 500 (Sumitomo Chemical Brasil Indústria Química S.A., Maracanaú, CE, Brazil), and Provado® 200 SC (Bayer S.A., São Paulo, SP, Brazil) were used, according to the manufacturers' instructions, and in preparing the spray mixture, the adjuvant Redu Mais (Fertiliza Biochemical, Avaré, SP, Brazil) was used.

2.4. Variables Analyzed

The stem diameter of the plants was evaluated twice, during the pruning of the main stem and at the end of the cycle. The diameter of the rootstock and scion was measured 5 cm from the grafting point, and the average of these latter values was then presented. For non-grafted plants, the stem diameter was measured 10 cm above ground level. These measurements were performed using a digital caliper (Tooleye®, Yiwu, China), and the results are expressed in millimeters. By evaluating the stem diameter at the time of main stem pruning and at the end of the cycle, the absolute and relative growth rates in stem diameter were calculated [38]. The duration of some phenophases of the crop was also recorded, such as the period between transplanting and pruning the main stem (PPMS) and the period of formation of secondary and productive branches (PFSPB), from the beginning to the end of the harvest—the productive phase (PF), from transplanting to the end of the harvest—crop cycle (CYCLE), all in days.

Harvesting began 153 days after transplanting the seedlings and continued for 153 days, three times a week, with the fruits collected from the ground, including those that easily detached from the plant. It is important to highlight that the harvests were carried out for only 5 months, 153 days exactly, but the yellow passion fruit crop can be harvested for up to 18 months [1,7]. In the last harvest, the productive branches were counted, considering those derived from the secondary branches, with results as branches

per plant. Based on the harvests, the following was determined: number of fruits per plant (NF), by dividing the total number of fruits by the number of plants in the subplot, with results as fruits per plant; average fruit mass (AFM), by the ratio between the total mass of fruits and the number of fruits in the subplot, with results expressed in grams; and crop yield (CY), through the product of the number of fruits per plant, average fruit mass, and population density, divided by 1000, expressed in kg ha^{-1} .

Using weekly productivity data, early ripening (ERI) and concentrated cultivation (CCI) indices were calculated according to Equations 1 and 2, respectively [39]:

$$\text{ERI} = \sum_{i=1}^n \left(\frac{Y_i}{D_i} \right) / n$$

where:

ERI = early ripening index;

$i = 1, 2, \dots, n$;

n = number of harvests;

Y_i = crop yield;

D_i = number of days from the start of the harvest to the end of the harvest.

$$\text{CCI} = \frac{\sqrt{\sum_{i=1}^n (Y_i - Y)^2 / n}}{n}$$

where:

CCI = concentrated cultivation index;

$i = 1, 2, \dots, n$;

n = number of harvests;

Y_i = percentage yield in the i -harvest;

Y = average percentage yield for number of harvests.

2.5. Statistical Analysis

The data were initially analyzed for normality of residuals (Anderson–Darling) and homogeneity of variances (Bartlett’s and Levene tests), based on the model residuals and considering $p \leq 0.05$, being transformed when these assumptions of analysis of variance are not met ($\log(x + 1)$ for continuous quantitative data, and $\sqrt{(x + 1)}$ for discrete quantitative data-counting). Next, an analysis of variance was performed (F-test and $p \leq 0.05$). The means of the grafted plants, in relation to the scions, rootstocks, and electrical conductivity of the irrigation water, were compared using Tukey’s test ($p \leq 0.05$), based on the unfolding of the analysis of variance. A comparison was also made between grafted and non-grafted plants, using the F-test ($p \leq 0.05$). For non-grafted *P. edulis*, Tukey’s test ($p \leq 0.05$) was also performed, comparing the varieties and the electrical conductivity of the irrigation water. Multivariate analyses were also performed, including principal component analysis and cluster analysis, based on treatment scores, with the aim of identifying patterns of variation and exploring the interrelationships between variables and treatments [40,41]. The analyses were performed using R[®] software version 4.4.0 [42].

3. Results

3.1. Development and Crop Cycle of Grafted and Non-Grafted *Passiflora Edulis* Under Saline Water Irrigation

The time of main stem pruning was influenced by the interaction between rootstock and scion ($F = 2.53$; $p = 0.0489$, $\text{CV}_{\text{subplot}} = 6.95\%$). The *P. foetida* rootstock reduced the number of days for pruning the main stem (Figure 4). The number of days for pruning

the main stem when grafting *P. edulis*, Guinezinho cultivar, onto *P. foetida* was 42 days, which was less than grafting onto *P. edulis*, Guinezinho cultivar (52 days), with an increase of 9 days, or onto *P. cincinnata* (64 days), with an increase of 22 days, with the latter combination resulting in the greatest delay in pruning. The number of days for pruning the main stem when grafting *P. edulis*, BRS YG1 cultivar, onto *P. foetida* was 44 days, which was less than grafting onto *P. cincinnata* (55 days) and *P. edulis*, Guinezinho cultivar (63 days), which did not differ from each other, with an average reduction of 15 days. The number of days for pruning the main stem when grafting *P. edulis*, BRS SC1 cultivar, onto *P. foetida* was 50 days, a shorter period compared to grafting onto *P. edulis*, cultivar Guinezinho (62 days), and *P. cincinnata* (63 days), which did not differ from each other and delayed grafting by 13 days. Regarding the scions, differences were observed in the number of days for pruning the main stem only when the rootstock was *P. edulis*, Guinezinho cultivar (Figure 4). Using the Guinezinho cultivar, the shortest time (52 days) was obtained, less than the days when the scions were of BRS SC1 (62 days) and BRS YG1 (63 days), which did not differ from each other, resulting in an average delay of 11 days.

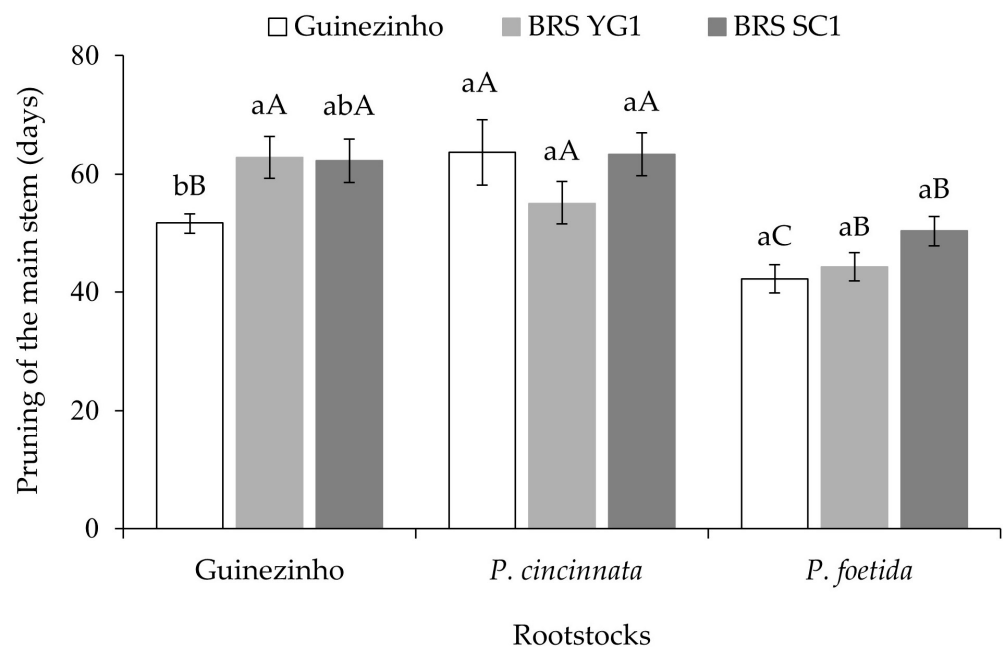


Figure 4. Mean values $\pm$ standard error of the number of days for the period between transplanting grafted seedlings and pruning the main stem of the plants in response to the *Passiflora* species used as rootstocks (Guinezinho, *P. cincinnata*, and *P. foetida*) and to the *P. edulis* cultivars used as scions (Guinezinho, BRS YG1, and BRS SC1). Means followed by the same letter, lowercase between scions and uppercase between rootstocks, do not differ from each other by Tukey's test ($p \leq 0.05$).

The *P. edulis* cultivars (Guinezinho, BRS YG1, and BRS SC1) as scions, irrigated with water at 0.5 or 3.0 dS m⁻¹, reduced the period for pruning the main stem to between 33 and 74 days (Table 5). While the non-grafted plants only showed the effect of the cultivar ($F = 16.71$; $p < 0.0001$; $CV_{\text{subplot}} = 6.95\%$), Guinezinho (92 days) was the earliest, followed by BRS YG1 (120 days) and BRS SC1 (124 days), which did not differ from each other.

The time it takes for secondary and productive branches to form was affected by both the rootstock ($F = 4.30$; $p = 0.0175$; $CV_{\text{subplot}} = 7.42\%$) and the scion ($F = 3.49$; $p = 0.0364$; $CV_{\text{subplot}} = 7.42\%$). Plants grafted onto *P. foetida* showed a greater number of days for the formation of secondary and productive branches (115 days), surpassing the time with the rootstocks of *P. edulis*, Guinezinho cultivar (107 days), and *P. cincinnata* (102 days), which did not differ from each other, and a reduction of 11 days was achieved when *P. foetida*

was used (Figure 5A). When using *P. edulis* scions from the BRS YG1 cultivar, a greater number of days for secondary branch formation was observed (115 days), exceeding the time obtained with the Guinezinho (106 days) and BRS SC1 (103 days) cultivars, which did not differ from each other, and exceeding the average of these last two cultivars by 11 days (Figure 5B).

Table 5. Effects of scions of *P. edulis* cultivar Guinezinho, BRS Yellow Giant (BRS YG1), and BRS Sun of Cerrado (BRS SC1) grafted onto *Passiflora* spp., and mean values $\pm$ standard error of these non-grafted cultivars, irrigated crops with water levels of 0.5 and 3.0 dS m⁻¹, regarding the number of days for pruning the main stem, for the formation of secondary and productive branches, for the productive phase, and for the crop cycle.

Cultivars	Guinezinho	BRS YG1	BRS SC1	Guinezinho	BRS YG1	BRS SC1
ECiw 0.5 dS m ^{−1}			ECiw 3.0 dS m ^{−1}			
Pruning of the main stem (days)						
Effect of grafting	−46 **	−74 **	−70 **	−33 **	−58 **	−60 **
Not grafted	96 ± 10 bA	125 ± 3 aA	125 ± 3 aA	88 ± 8 bA	115 ± 4 aA	122 ± 2 aA
Formation of secondary and productive branches (days)						
Effect of grafting	16 ^{ns}	46 **	28 **	12 ^{ns}	−13 ^{ns}	19 *
Not grafted	92 ± 9 aA	69 ± 5 aB	78 ± 16 aA	93 ± 14 abA	127 ± 14 aA	81 ± 5 bA
Productive phase (days)						
Effect of grafting	27 ^{ns}	26 ^{ns}	40 **	23 ^{ns}	83 **	44 **
Not grafted	111 ± 17 aA	104 ± 4 aA	91 ± 22 aA	117 ± 5 aA	43 ± 17 bB	83 ± 6 aA
Cycle (days)						
Effect of grafting	−3 ^{ns}	−2 ^{ns}	−1 ^{ns}	2 ^{ns}	12*	4 ^{ns}
Not grafted	299 ± 5 aA	299 ± 2 aA	294 ± 5 aA	298 ± 3 aA	286 ± 5 aA	285 ± 4 aA

^{ns}, * and **: not significant and significant at 5% and 1% probability levels according to the F-test, respectively (real effect of the contrast between grafted and non-grafted plants). Means followed by the same letter, lowercase between cultivars and uppercase between electrical conductivity of irrigation water, do not differ from each other by Tukey's test ($p \leq 0.05$).

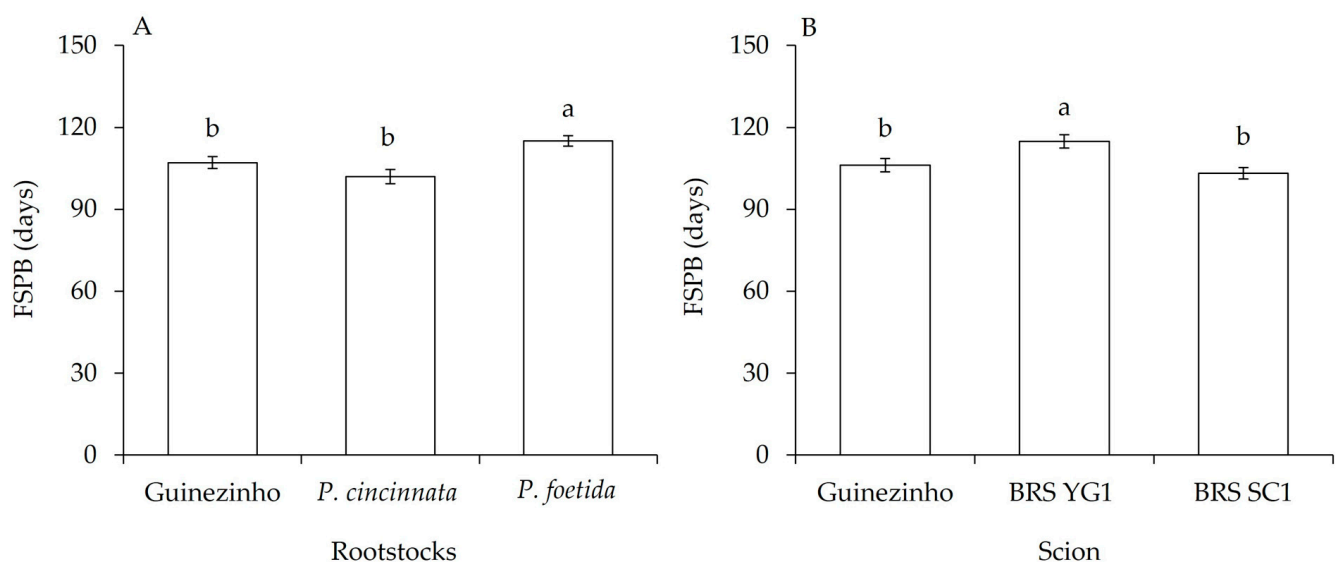


Figure 5. Mean values $\pm$ standard error of the number of days for the formation of secondary and productive branches (FSPB) in response to the *Passiflora* species used as rootstocks (Guinezinho, *P. cincinnata*, and *P. foetida*) (A) and to the *P. edulis* cultivars used as scions (Guinezinho, BRS YG1, and BRS SC1) (B). Means followed by the same lowercase letter do not differ from each other by Tukey's test ($p \leq 0.05$).

The *P. edulis* BRS YG1 and BRS SC1 cultivars, used as scions and under irrigation with water at 0.5 dS m^{-1} , increased the number of days for the formation of secondary and productive branches by 46 and 28 days, respectively (Table 5). However, under irrigation with water at 3.0 dS m^{-1} , this effect was observed only with the BRS SC1 cultivar with an additional 19 days. For the Guinezinho cultivar, under irrigation with water at 0.5 or 3.0 dS m^{-1} , no alteration was observed in the formation time of secondary and productive branches when grafting. It was also observed that in non-grafted plants, the interaction effect between varieties and the electrical conductivity of irrigation water was significant ($F = 9.30$; $p = 0.0003$; $\text{CV}_{\text{plot}} = 4.40\%$; $\text{CV}_{\text{subplot}} = 7.42\%$). Under irrigation with water at 0.5 dS m^{-1} , no differences were observed between the cultivars, with an average of 80 days for the formation of secondary and productive branches (Table 5). Meanwhile, when irrigating with water at 3.0 dS m^{-1} , the longest time was obtained with the BRS YG1 cultivar (127 days), which did not differ from the Guinezinho cultivar (93 days) but surpassed the BRS SC1 cultivar (81 days). The electrical conductivity of the irrigation water only altered the pattern for the BRS YG1 cultivar, increasing from 69 days under a conductivity of 0.5 dS m^{-1} to 127 days under irrigation with water of 3.0 dS m^{-1} .

For the duration of the productive phase of grafted *P. edulis*, no effect of the scion, rootstock, or electrical conductivity of the irrigation water was observed, either in isolation or in interaction ($F \leq 1.34$; $p \geq 0.2690$; $\text{CV}_{\text{plot}} = 14.20\%$; $\text{CV}_{\text{subplot}} = 10.08\%$), with an average of 122 ± 3 days. It was also observed that grafting increased the duration of the productive phase of the BRS SC1 cultivar irrigated with water at 0.5 dS m^{-1} and 3.0 dS m^{-1} by 40 days and 44 days, respectively (Table 5). With the BRS YG1 cultivar, this phase also increased by 83 days, but only under irrigation with water at 3.0 dS m^{-1} . In the Guinezinho cultivar, no alteration resulting from grafting was observed. However, non-grafted plants were influenced by the interaction between cultivar and electrical conductivity of irrigation water ($F = 10.41$; $p = 0.0001$; $\text{CV}_{\text{plot}} = 14.20\%$; $\text{CV}_{\text{subplot}} = 10.08\%$). For these plants, irrigated with water at 0.5 dS m^{-1} , no difference was observed in the productive phase, with an average of 102 days (Table 5). However, when irrigated with water at 3.0 dS m^{-1} , a reduction was observed for the BRS YG1 cultivar (43 days) compared to the Guinezinho cultivar (117 days) and the BRS SC1 cultivar (83 days), which did not differ from each other.

The duration of the cycle of grafted *P. edulis* plants was influenced only by the scion ($F = 3.59$; $p = 0.0332$; $\text{CV}_{\text{subplot}} = 3.38\%$), but the means did not differ by Tukey's test ($p \leq 0.05$), with an average duration of 295 ± 1 days. Only with the BRS YG1 cultivar, when irrigated with water at 3.0 dS m^{-1} , was an increase in the crop cycle observed, estimated at 12 days (Table 5). With the other cultivars and electrical conductivity of irrigation water, the differences with grafting were not significant. With non-grafted *P. edulis*, the effects of cultivar and electrical conductivity of irrigation water, individually and in interaction, were not significant ($F \leq 3.26$; $p \geq 0.0752$; $\text{CV}_{\text{plot}} = 4.07\%$; $\text{CV}_{\text{subplot}} = 3.38\%$), with a mean of 293 ± 2 days.

3.2. Stem Diameter and Stem Diameter Growth Rates of Grafted and Non-Grafted *Passiflora Edulis* Under Saline Water Irrigation

The stem diameter, when the grafted plants reached the trellis, was affected by the rootstock ($F = 19.02$; $p \leq 0.0001$, $\text{CV}_{\text{subplot}} = 9.62\%$) and the scion ($F = 22.28$; $p \leq 0.0001$, $\text{CV}_{\text{subplot}} = 9.62\%$). Plants with *P. edulis* Guinezinho cultivar rootstock showed a larger diameter (9.28 mm), exceeding the values obtained with *P. cincinnata* (8.67 mm) and *P. foetida* (7.68 mm), with estimated reductions of 6.57% and 17.24%, respectively (Figure 6A). Regarding *P. edulis* scions, the largest diameter was obtained using the BRS SC1 cultivar (9.56 mm), surpassing the Guinezinho (7.87 mm) and BRS YG1 (8.20 mm) cultivars, which did not differ from each other (Figure 6B).

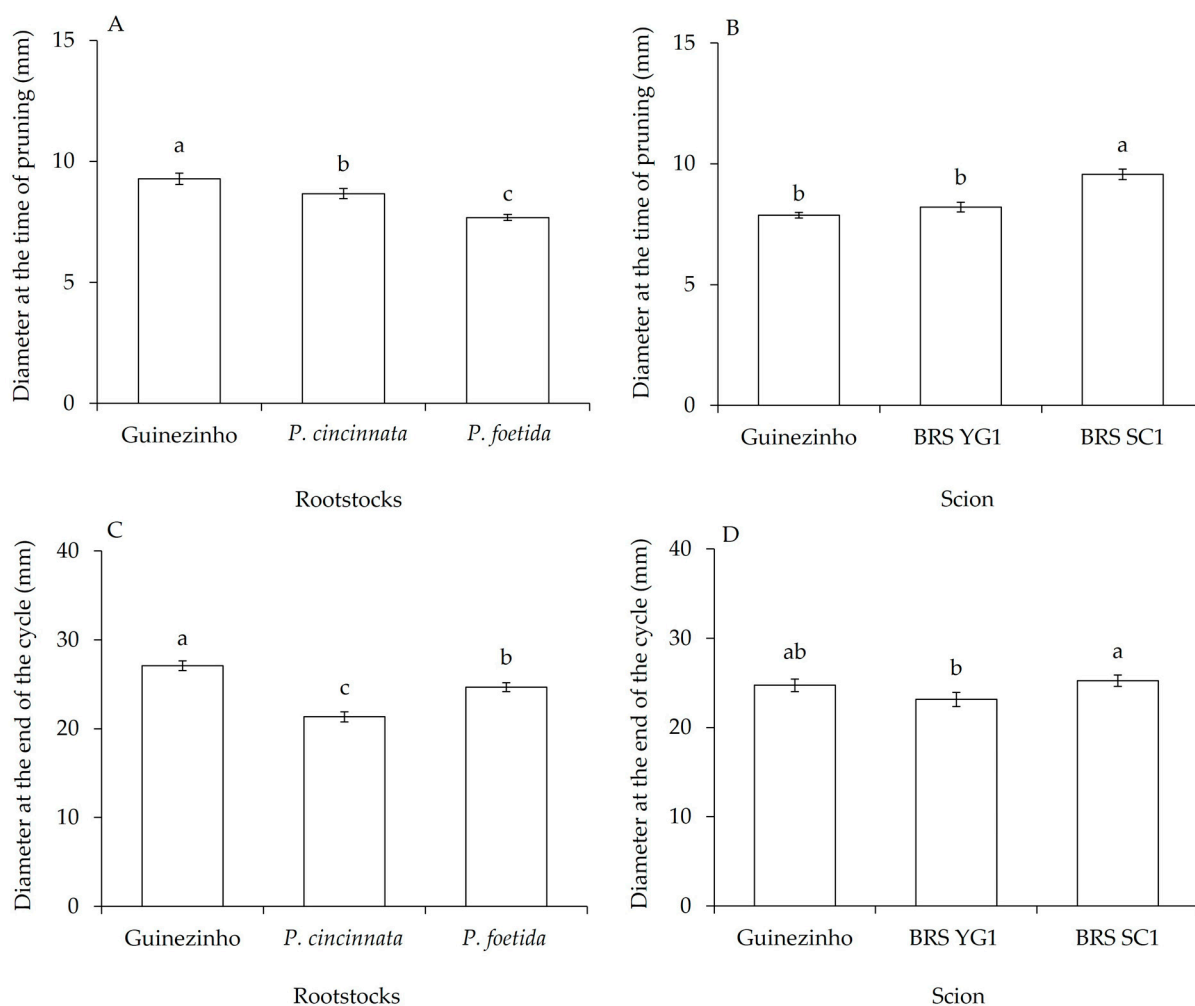


Figure 6. Mean values $\pm$ standard error of stem diameter at the time of main stem pruning, in response to the *Passiflora* species used as rootstocks (Guinezinho, *P. cinnamomum* and *P. foetida*) (A) and to the *P. edulis* cultivars used as scions (Guinezinho, BRS YG1 and BRS SC1) (B), and at the end of the cycle, in relation to the *Passiflora* species used as rootstock (Guinezinho, *P. cinnamomum* and *P. foetida*) (C) and to the *P. edulis* cultivars used as scion (Guinezinho, BRS YG1 and BRS SC1) (D). Means followed by the same lowercase letter do not differ from each other by Tukey's test ($p \leq 0.05$).

When grafting *P. edulis*, a reduction in stem diameter was observed at the time of pruning the main stem only when using the Guinezinho cultivar as scion, irrigated with water at 0.5 dS m^{-1} or 3.0 dS m^{-1} (Table 6). Differences in stem diameter growth at pruning time were also observed only as a function of the variety ($F = 8.85$; $p = 0.0004$; $\text{CV}_{\text{subplot}} = 9.62\%$) of non-grafted *P. edulis*. The largest values were observed with the Guinezinho cultivar (9.85 mm), followed by the BRS SC1 cultivar (8.77 mm), not differing from each other, and the smallest diameter was observed in the BRS YG1 cultivar (7.84 mm), differing only from the Guinezinho cultivar (Table 6).

The diameter growth of the plants, at the end of the cycle, was affected by the rootstock ($F = 24.63$; $p \leq 0.0001$, $\text{CV}_{\text{subplot}} = 11.74\%$) and the scion ($F = 3.56$; $p = 0.0341$, $\text{CV}_{\text{subplot}} = 11.74\%$). The diameter of the plants is related to the rootstock, differing between them, with the *P. edulis* Guinezinho cultivar having the largest diameter (27.10 mm), followed by *P. foetida* (24.68 mm) and *P. cinnamomum* (21.33 mm) (Figure 6C). Regarding the scions of *P. edulis*, when using the BRS SC1 and Guinezinho cultivars, the largest diameters were obtained (25.26 and 24.72 mm, respectively), not differing from each other, while with the BRS YG1 cultivar, the smallest diameter was obtained (23.14 mm); however, it did not

differ from the Guinezinho cultivar and was 8.39% smaller when the BRS SC1 cultivar was used (Figure 6D).

Table 6. Effects of scions of *P. edulis* cultivar Guinezinho, BRS Yellow Giant (BRS YG1), and BRS Sun of Cerrado (BRS SC1) grafted onto *Passiflora* spp., and mean values $\pm$ standard error of these non-grafted cultivars, irrigated crops with water levels of 0.5 and 3.0 dS m⁻¹, regarding the stem diameter of the plants at the time of pruning, at the end of the cycle, and the absolute and relative growth rate in stem diameter of the passion fruit plant.

Cultivars	Guinezinho	BRS YG1	BRS SC1	Guinezinho	BRS YG1	BRS SC1
ECiw 0.5 dS m ⁻¹			ECiw 3.0 dS m ⁻¹			
Stem diameter of the plants at the time of pruning (mm)						
Effect of grafting	−2.62 **	0.46 ^{ns}	0.8 ^{ns}	−1.34 **	0.27 ^{ns}	0.76 ^{ns}
Not grafted	10.45 ± 0.52 aA	7.75 ± 0.64 bA	8.67 ± 0.14 abA	9.25 ± 1.1 aA	7.92 ± 0.38 bA	8.87 ± 1.09 abA
Stem diameter at the end of the cycle (mm)						
Effect of grafting	−1.97 ^{ns}	3.44 *	−0.01 ^{ns}	0.77 ^{ns}	0.36 ^{ns}	−2.74 ^{ns}
Not grafted	25.78 ± 1.40 abA	19.62 ± 1.81 bA	24.40 ± 1.15 aA	24.86 ± 1.32 abA	22.85 ± 2.11 bA	28.86 ± 2.67 aA
Absolute growth rate in stem diameter (mm dia ⁻¹)						
Effect of grafting	−0.1 ^{ns}	0.0 ^{ns}	−0.2 **	0.0 ^{ns}	−0.2 *	−0.3 **
Not grafted	0.06 ± 0.005 bA	0.06 ± 0.006 bA	0.08 ± 0.006 aA	0.06 ± 0.003 bA	0.07 ± 0.010 bA	0.10 ± 0.011 aA
Relative growth rate in stem diameter (mm mm ⁻¹ dia ⁻¹)						
Effect of grafting	0.0 ^{ns}	−0.4 *	−0.7 **	0.0 ^{ns}	−0.5 **	−0.9 **
Not grafted	0.0016 ± 0.00007 bA	0.0019 ± 0.0001 abA	0.0021 ± 0.0001 aA	0.0018 ± 0.0001 bA	0.0021 ± 0.0002 abA	0.0025 ± 0.0003 aA

^{ns}, * and **: not significant and significant at 5% and 1% probability levels according to the F-test, respectively (real effect of the contrast between grafted and non-grafted plants). Means followed by the same letter, lowercase between cultivars and uppercase between electrical conductivity of irrigation water, do not differ from each other by Tukey's test ($p \leq 0.05$).

Grafting also affected stem diameter growth, measured at the end of the cycle, but only it only increased when using the BRS YG1 cultivar as scion and irrigated with water at 0.5 dS m⁻¹ (Table 6). Differences in stem diameter growth were also observed at the end of the cycle, but only as a function of the variety ($F = 7.83$; $p = 0.0009$; $CV_{\text{subplot}} = 11.74\%$) of non-grafted *P. edulis*. The largest diameters were recorded with the BRS SC1 (26.63 mm) and Guinezinho (25.32 mm) cultivars, which did not differ from each other, and the smallest value was observed with the BRS YG1 (21.24 mm) cultivar, which was lower than that obtained with the BRS SC1 cultivar (Table 6).

The absolute growth rate of stem diameter was affected only by the rootstock ($F = 16.11$; $p \leq 0.0001$, $CV_{\text{subplot}} = 34.35\%$), with the highest rates for *P. edulis* Guinezinho cultivar and the species *P. foetida* (0.064 mm day⁻¹ and 0.059 mm day⁻¹, respectively), not differing from each other, while *P. cincinnata* showed the lowest growth rate (Figure 7A). It was also observed that using scions of the BRS SC1 cultivar, irrigated with water at 0.5 dS m⁻¹ and 3.0 dS m⁻¹, and the BRS YG1 cultivar, irrigated with water at 3.0 dS m⁻¹, reduced the absolute growth rate of plant diameter compared to non-grafted plants (Table 6). These non-grafted *P. edulis* cultivars differed from each other ($F = 10.59$; $p = 0.0001$; $CV_{\text{subplot}} = 34.35\%$), and an effect of the electrical conductivity of the irrigation water ($F = 5.46$; $p = 0.0224$; $CV_{\text{plot}} = 18.26\%$) on the absolute stem growth rate was observed. The highest absolute stem growth rate was observed with the BRS SC1 cultivar (0.09 mm day⁻¹), and the lowest rates were observed with the Guinezinho and BRS YG1 cultivars (0.06 mm day⁻¹ and 0.06 mm day⁻¹, respectively), which did not differ from each other (Table 6). Regarding the electrical conductivity of irrigation water, the highest absolute growth rate in diameter was obtained with water of 0.5 dS m⁻¹ (0.07 mm day⁻¹), lower than that obtained with water at 3.0 dS m⁻¹ (0.08 mm day⁻¹).

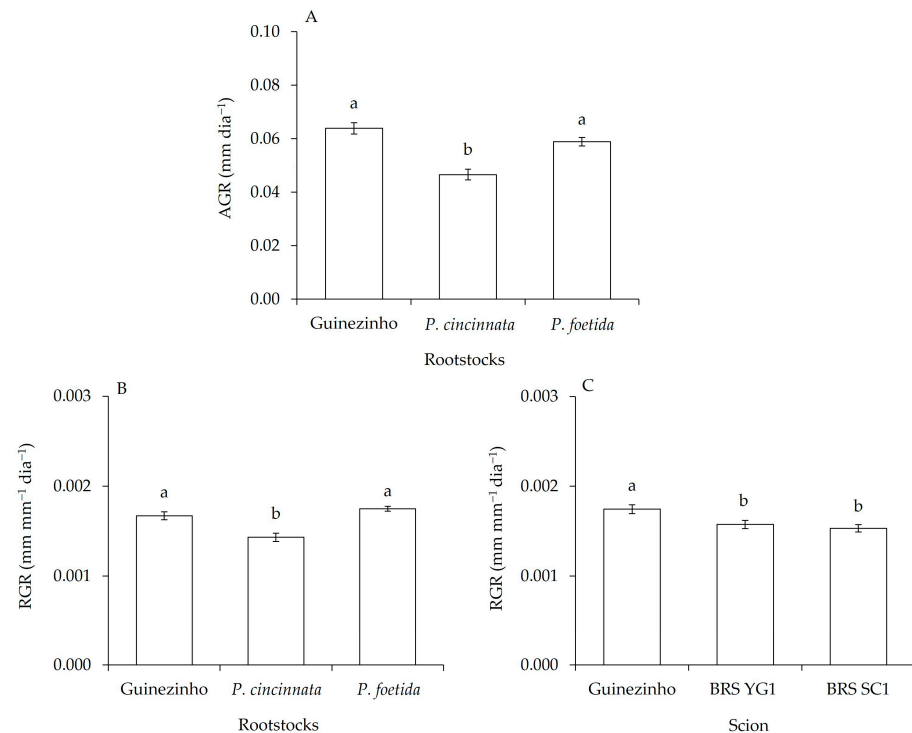


Figure 7. Mean values $\pm$ standard error of the absolute growth rate—AGR (A), in relation to the *Passiflora* species used as rootstock (Guinezinho, *P. cincinnata* and *P. foetida*), and relative growth rate—RGR, in relation to the *Passiflora* species used as rootstocks (Guinezinho, *P. cincinnata* and *P. foetida*), (B) and in relation to the *P. edulis* cultivars used as scions (Guinezinho, BRS YG1 and BRS SC1) (C), of the stem diameter. Means followed by the same lowercase letter do not differ from each other by Tukey's test ($p \leq 0.05$).

The relative growth rate of plant stem diameter was affected by both the rootstock ($F = 11.47$; $p \leq 0.0001$, $CV_{\text{subplot}} = 35.05\%$) and the scion ($F = 5.04$; $p = 0.0092$, $CV_{\text{subplot}} = 35.05\%$). Regarding the rootstock, the highest rates were observed with the Guinezinho cultivar and the *P. foetida* species ($0.00167 \text{ mm mm}^{-1} \text{ day}^{-1}$ and $0.00175 \text{ mm mm}^{-1} \text{ day}^{-1}$, respectively), not differing from each other, while the lowest rate of $0.00143 \text{ mm mm}^{-1} \text{ day}^{-1}$ was recorded with *P. cincinnata* (Figure 7B). When using the *P. edulis* scion of the Guinezinho cultivar, the highest relative growth rate of stem diameter was obtained ($0.00174 \text{ mm mm}^{-1} \text{ day}^{-1}$), surpassing that obtained when using the BRS YG1 ($0.00158 \text{ mm mm}^{-1} \text{ day}^{-1}$) and BRS SC1 ($0.00153 \text{ mm mm}^{-1} \text{ day}^{-1}$) cultivars, which did not differ from each other (Figure 7C). Reductions in stem diameter growth rate were also observed in the BRS YG1 and BRS SC1 cultivars of *P. edulis*, irrigated with water at 0.5 dS m^{-1} or 3.0 dS m^{-1} , compared to non-grafted plants (Table 6). The non-grafted *P. edulis* cultivars differed from each other ($F = 12.56$; $p < 0.0001$; $CV_{\text{subplot}} = 35.05\%$), and the electrical conductivity of the irrigation water ($F = 5.47$; $p = 0.0223$; $CV_{\text{plot}} = 29.90\%$) also altered the relative stem growth rate.

The highest rates were observed with the BRS YG1 ($0.0020 \text{ mm mm}^{-1} \text{ day}^{-1}$) and BRS SC1 ($0.0023 \text{ mm mm}^{-1} \text{ day}^{-1}$) cultivars, which did not differ from each other, while the lowest rate was recorded with the Guinezinho cultivar ($0.0017 \text{ mm mm}^{-1} \text{ day}^{-1}$), differing only from BRS SC1 (Table 6). The increase in the electrical conductivity of the irrigation water raised the relative growth rate in stem diameter of the plants, with an average of $0.0019 \text{ mm mm}^{-1} \text{ day}^{-1}$ under irrigation with water at 0.5 dS m^{-1} , and $0.0021 \text{ mm mm}^{-1} \text{ day}^{-1}$ when irrigated with water at 3.0 dS m^{-1} (Table 6).

3.3. Yield Components, Productivity, and Production Earliness Indices of Grafted and Non-Grafted *Passiflora Edulis* Under Saline Water Irrigation

The number of fruits per plant was affected by the interaction between the electrical conductivity of the irrigation water, rootstock, and scion ($F = 4.57$; $p = 0.0026$, $CV_{\text{plot}} = 11.70\%$; $CV_{\text{subplot}} = 13.12\%$). The highest number of fruits was obtained under irrigation with water at 3.0 dS m^{-1} in plants of the *P. foetida*, as rootstock, and *P. edulis* BRS YG1 cultivar (50 fruits), as scion (Figure 8). Increasing the electrical conductivity of irrigation water to 3.0 dS m^{-1} increased the number of fruits of *P. edulis* scion of the BRS YG1 cultivar onto *P. foetida* under irrigation with water at 0.5 dS m^{-1} ; the number of fruits per plant was 31, and under water at 3.0 dS m^{-1} , 50 fruits per plant were produced, an increase of 61.29%. However, for the BRS YG1 cultivar grafted onto the Guinezinho cultivar, there was a reduction from 34 fruits per plant under water at 0.5 dS m^{-1} to 19 fruits under water at 3.0 dS m^{-1} , a reduction of 44.12%. Regarding the rootstocks, these only differed under irrigation with water of 3.0 dS m^{-1} and when the *P. edulis* scion of the BRS YG1 cultivar was used, where the highest number of fruits was obtained with the *P. foetida* rootstock (50 fruits), exceeding those obtained with the Guinezinho (19 fruits) and *P. cincinnata* (26 fruits) rootstocks by 163.16% and 93.31%, respectively (Figure 8). The number of fruits per plant only differed between scions of *P. edulis* cultivars when grafted onto *P. foetida* and irrigated with water at 3.0 dS m^{-1} , where the highest number was obtained in plants grafted with the BRS YG1 cultivar (50 fruits), exceeding those obtained with the Guinezinho (25 fruits) and BRS SC1 (22 fruits) cultivars by 100.00% and 127.27%, respectively (Figure 8).

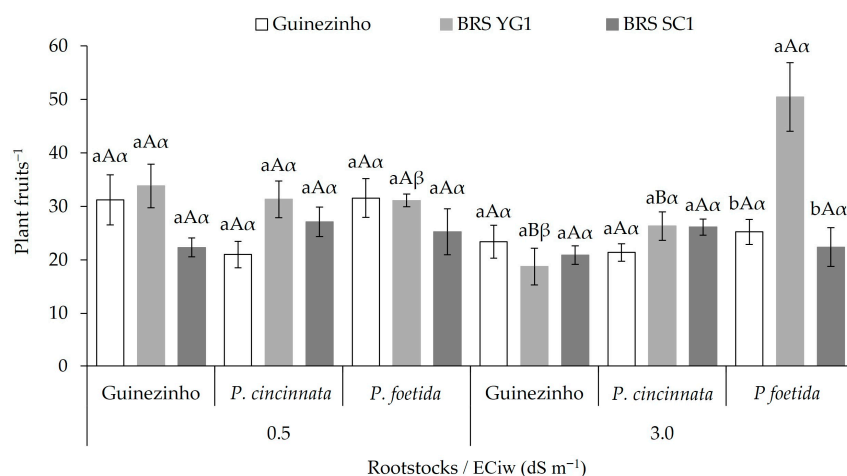


Figure 8. Mean values $\pm$ standard error of the number of passion fruit per plant in response to the electrical conductivity of irrigation water—ECiw (0.5 and 3.0 dS m^{-1}), of the *Passiflora* species used as rootstocks (Guinezinho, *P. cincinnata* and *P. foetida*), and of the *P. edulis* cultivars used as scions (Guinezinho, BRS YG1 and BRS SC1). Means followed by the same letter, lowercase between scions, uppercase between rootstocks, and Greek letters between irrigation water electrical conductivity, do not differ from each other by Tukey's test ($p \leq 0.05$).

The *P. edulis* Guinezinho, BRS YG1 and BRS SC1 cultivars, as scions, under irrigation with water at 0.5 dS m^{-1} and 3.0 dS m^{-1} , produced a greater number of fruits per plant when compared with these cultivars without grafting (Table 7). It was also observed that there was an interaction between the non-grafted *P. edulis* cultivars and the electrical conductivity of the irrigation water ($F = 36.79$; $p = 0.0303$; $CV_{\text{plot}} = 11.70\%$; $CV_{\text{subplot}} = 13.12\%$). The highest number of fruits was obtained with the Guinezinho cultivar (16 fruits), surpassing the number obtained with the BRS YG1 (5 fruits) and BRS SC1 (4 fruits) cultivars, which did not differ from each other (Table 7).

Table 7. Effects of scions of *P. edulis* Guinezinho, BRS Yellow Giant (BRS YG1), and BRS Sun of Cerrado (BSR SC1) cultivars grafted onto *Passiflora* spp. and mean values $\pm$ standard error of these non-grafted cultivars, irrigated crops with water levels of 0.5 and 3.0 dS m⁻¹, regarding the fruits per plant, average fruit weight, yield, productive branches per plant, early ripening index (ERI), and concentrated cultivation index (CCI).

Cultivars	Guinezinho	BRS YG1	BRS SC1	Guinezinho	BRS YG1	BRS SC1
	ECiw 0.5 dS m ^{−1}			ECiw 3.0 dS m ^{−1}		
	Fruits per plant (unit)					
Effect of grafting	10 **	24 **	21 **	10 **	31 **	19 **
Not grafted	18 ± 2.6 aA	8 ± 2.5 bA	4 ± 0.9 bA	13 ± 3.0 aA	1 ± 0.1 cB	4 ± 0.2 bA
	Average fruit weight (g)					
Effect of grafting	−2.49 ^{ns}	−6.41 ^{ns}	14.11 ^{ns}	5.47 ^{ns}	9.56 ^{ns}	−17.06 *
Not grafted	143.93 ± 8.10 aA	110.95 ± 4.27 bA	120.27 ± 10.84 abB	137.60 ± 13.64 aA	86.94 ± 3.44 bB	154.82 ± 10.82 aA
	Yield (kg ha ^{−1})					
Effect of grafting	2207.9 **	4153.8 **	4803.7 **	2672.2 **	4979.5 **	4166.4 **
Not grafted	4298.9 ± 591.0 aA	1485.2 ± 434.2 bA	751.1 ± 175.04 bA	2878.9 ± 600.9 aA	102.9 ± 11.0 bA	1131.0 ± 50.6 bA
	Productive branches per plant (unit)					
Effect of grafting	2 ^{ns}	1 ^{ns}	2 ^{ns}	1 ^{ns}	0 ^{ns}	1 ^{ns}
Not grafted	20 ± 0.9 aA	23 ± 1.6 aA	21 ± 1.3 aA	22 ± 0.2 aA	22 ± 1.2 aA	22 ± 1,95 aA
	Early ripening index—ERI (kg ha ^{−1} dia ^{−1})					
Effect of grafting	11.05 **	4.19 **	7.18 **	9.36 **	4.28 **	6.95 **
Not grafted	2.77 ± 1.030 aA	0.43 ± 0.131 bA	0.20 ± 0.038 bA	2.73 ± 0.752 aA	0.04 ± 004 bA	0.84 ± 0.084 bA
	Concentrated cultivation index—CCI					
Effect of grafting	−0.07 *	−0.13 **	−0.30 **	−0.03 ^{ns}	−0.49 **	−0.10 **
Not grafted	0.40 ± 0.05 bA	0.47 ± 0.03 bB	0.64 ± 0.05 aA	0.33 ± 0.02 cA	0.80 ± 0.06 aA	0.47 ± 0.03 bB

^{ns}, * and **: not significant and significant at 5% and 1% probability levels according to the F-test, respectively (real effect of the contrast between grafted and non-grafted plants). Means followed by the same letter, lowercase between cultivars and uppercase between electrical conductivity of irrigation water, do not differ from each other by Tukey's test ($p \leq 0.05$).

The average fruit mass was affected by the passionflower species used as rootstock ($F = 8.03$; $p = 0.0008$, $CV_{\text{subplot}} = 10.92\%$) and the *P. edulis* varieties used as scion ($F = 64.05$; $p \leq 0.0001$, $CV_{\text{subplot}} = 10.92\%$). The highest average fruit mass occurred in the fruits of plants with the Guinezinho cultivar rootstock (135.44 g) of the *P. edulis* species, being 10.54% and 12.03% higher than those obtained from the *P. cincinnata* (122.52 g) and *P. foetida* (120.89 g) species, respectively, which did not differ from each other (Figure 9A). The highest average passion fruit masses occurred when harvested from plants grafted with the Guinezinho (142.25 g) and BRS SC1 (136.07 g) cultivars, which did not differ from each other, and were higher than the average mass of the fruits from plants grafted with the cultivar BRS YG1 (100.52 g), with an average reduction of 27.8% (Figure 9B).

Grafting of *P. edulis* cultivars only affected the average mass of passion fruit when the BRS SC1 cultivar was used and irrigated with water at 3.0 dS m⁻¹, with an average reduction of 17.06 g per fruit (Table 7). It was also observed that there was an interaction between the non-grafted *P. edulis* cultivars and the electrical conductivity of the irrigation water ($F = 9.73$; $p = 0.0002$; $CV_{\text{plot}} = 7.30\%$; $CV_{\text{subplot}} = 10.93\%$). The highest fruit masses were obtained with the BRS SC1 (154.82 g) and Guinezinho (137.60 g) cultivars when the plants were irrigated with water at 3.0 dS m⁻¹, not differing from each other and exceeding the mass of fruits harvested from the BRS YG1 cultivar (Table 7). It was also observed that reducing the electrical conductivity of the irrigation water, from 3.0 dS m⁻¹ to 0.5 dS m⁻¹, did not cause any change in the average mass of the Guinezinho passion fruit cultivar, but reduced it by 22.3% for the BRS SC1 cultivar and increased it by 27.6% for the BRS YG1 cultivar. Under irrigation with water at 0.5 dS m⁻¹, the highest average passion fruit masses

were obtained with the Guinezinho (143.93 g) and BRS SC1 (120.27 g) cultivars, which did not differ from each other, and the latter did not differ from the BRS YG1 cultivar (110.95 g).

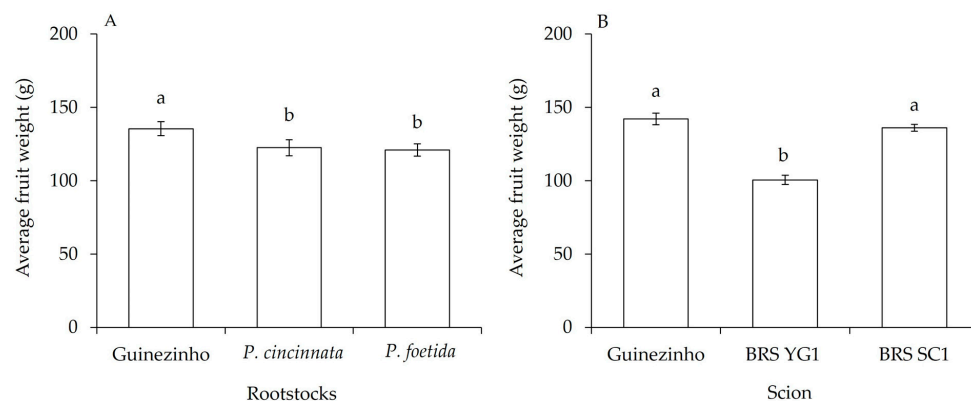


Figure 9. Mean values $\pm$ standard error of passion fruit mass in response to the *Passiflora* species used as rootstocks (Guinezinho, *P. cincinnata* and *P. foetida*) (A) and to the *P. edulis* cultivar used as scions (Guinezinho, BRS YG1 and BRS SC1) (B). Means followed by the same lowercase letter do not differ from each other by Tukey's test ($p \leq 0.05$).

Yield was affected by the interaction between the factors of electrical conductivity of irrigation water, passionflower species as rootstock, and *P. edulis* cultivars as scion ($F = 3.14$; $p = 0.0199$, $CV_{\text{plot}} = 25.86\%$; $CV_{\text{subplot}} = 31.19$). The highest productivity was obtained with the BRS YG1 cultivar grafted onto the *P. foetida* species and irrigated with water at 3.0 dS m^{-1} , with an average of $8073.96 \text{ kg ha}^{-1}$ (Figure 10). Increasing the electrical conductivity of irrigation water to 3.0 dS m^{-1} increased the productivity of the BRS YG1 cultivar grafted onto *P. foetida* by 56.27%, from $5166.51 \text{ kg ha}^{-1}$ irrigated with water of 0.5 dS m^{-1} to $8073.96 \text{ kg ha}^{-1}$ under irrigation with water of 3.0 dS m^{-1} , while for the BRS YG1 cultivar grafted onto *P. edulis* Guinezinho cultivar, there was a reduction from $6995.48 \text{ kg ha}^{-1}$ when using irrigation water with 0.5 dS m^{-1} to 3375.58 when irrigating with water of 3.0 dS m^{-1} , a reduction of 51.75%.

Regarding the rootstocks of the passionflower species, these only differed under irrigation with water of 3.0 dS m^{-1} and when the scion of the BRS YG1 cultivar of *P. edulis* was used, where the highest yield was obtained with the *P. foetida* rootstock ($8073.96 \text{ kg ha}^{-1}$), exceeding those obtained with *P. edulis* rootstocks of the Guinezinho cultivar ($3375.58 \text{ kg ha}^{-1}$) and *P. cincinnata* ($3797.75 \text{ kg ha}^{-1}$) by 139.19% and 112.60%, respectively (Figure 10). Yield only differed between scions when grafted onto *P. foetida* and irrigated with water at 3.0 dS m^{-1} , where the highest yield was obtained with the scion of the BRS YG1 cultivar ($8073.96 \text{ kg ha}^{-1}$), with no significant difference in productivity compared to the Guinezinho cultivar ($5813.62 \text{ kg ha}^{-1}$), but with a productivity 57.93% higher than that obtained with the BRS SC1 cultivar ($5112.26 \text{ kg ha}^{-1}$), without a significant difference between the productivity of the Guinezinho and BRS SC1 cultivars (Figure 10).

The Guinezinho, BRS YG1, and BRS SC1 cultivars, when grafted under irrigation with water of 0.5 dS m^{-1} and 3.0 dS m^{-1} , resulted in higher yield than when cultivated without grafting, with an increase between $2207.9 \text{ kg ha}^{-1}$ and $4979.5 \text{ kg ha}^{-1}$ (Table 7). For non-grafted plants, the *P. edulis* cultivars showed differences between them ($F = 9.55$; $p = 0.0002$; $CV_{\text{plot}} = 31.19\%$), with the highest average for the Guinezinho cultivar ($3588.9 \text{ kg ha}^{-1}$), exceeding the averages of the BRS YG1 (794.1 kg ha^{-1}) and BRS SC1 (941.1 kg ha^{-1}) cultivars, which did not differ from each other (Table 7). No significant variation in productivity was observed in relation to the electrical conductivity of the irrigation water ($F \leq 1.89$; $p \geq 0.1739$; $CV_{\text{plot}} = 25.86\%$).

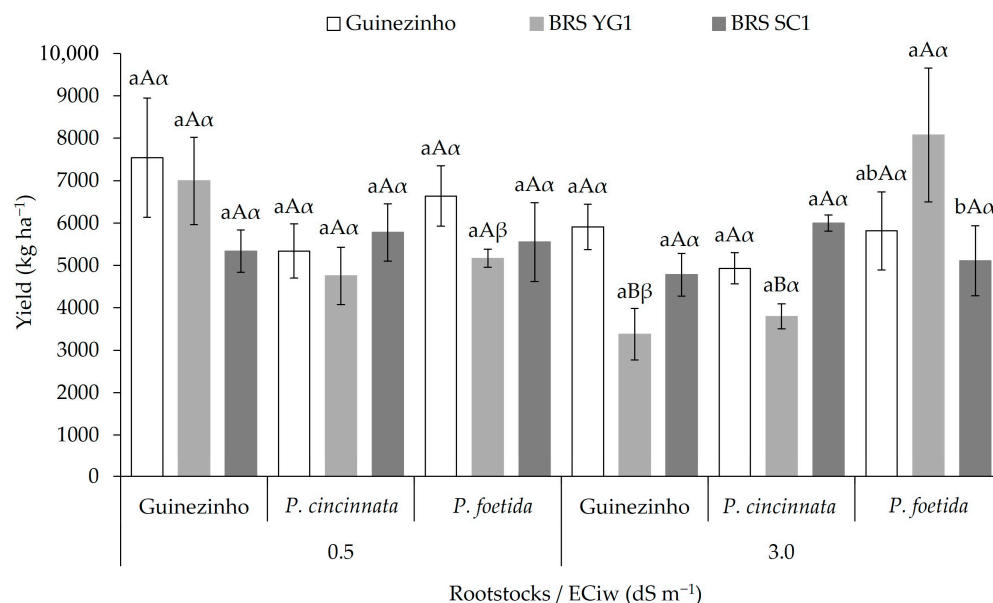


Figure 10. Mean values $\pm$ standard error of yield of the passion fruit plant in response to the electrical conductivity of irrigation water—ECiw (0.5 and 3.0 dS m⁻¹), of the *Passiflora* species used as rootstocks (Guinezinho, *P. cincinnata* and *P. foetida*), and of the *P. edulis* cultivars used as scions (Guinezinho, BRS YG1 and BRS SC1). Means followed by the same letter, lowercase between scions, uppercase between rootstocks, and Greek letters between irrigation water electrical conductivity, do not differ from each other by Tukey's test ($p \leq 0.05$).

The number of productive branches per plant, in grafted plants, was not affected by the electrical conductivity of the irrigation water, the rootstock, and the scion, either individually or in interaction ($F \leq 1.38$; $p \geq 0.2594$; $CV_{\text{plot}} = 14.37\%$; $CV_{\text{subplot}} = 9.13\%$), with an average of 22 ± 0.3 productive branches. No gain was observed with grafting (Table 7). Non-grafted *P. edulis* cultivars also did not differ and were not affected by the electrical conductivity of the irrigation water ($F \leq 1.39$; $p \geq 0.2553$; $CV_{\text{plot}} = 14.37\%$; $CV_{\text{subplot}} = 9.13\%$; Table 7), with an average of 22 ± 0.5 productive branches.

The early ripening index was affected by the interaction between the electrical conductivity of the irrigation water, the passionflower species used as rootstock, and the *P. edulis* cultivars used as scion ($F = 2.56$; $p = 0.0466$; $CV_{\text{plot}} = 63.79\%$; $CV_{\text{subplot}} = 56.14\%$). The highest rates of early ripening occurred when the Guinezinho cultivar of *P. edulis* was used as a scion, with the highest value in the combination where the Guinezinho cultivar was grafted onto *P. foetida* with irrigation at 0.5 dS m⁻¹, estimated at 20.02 (Figure 11A). The use of saline water in plant irrigation reduced the early ripening index only in plants of the BRS YG1 cultivar when grafted onto the Guinezinho cultivar, with an average of 5.19 when irrigated with water of 0.5 dS m⁻¹ to an average of 2.09 under irrigation with water of 3.0 dS m⁻¹, a reduction of 59.73% (Figure 11A). Under irrigation with water at 0.5 dS m⁻¹, the highest rates of early ripening occurred in plants of the Guinezinho cultivar grafted onto *P. foetida* (20.02), higher than the values obtained on grafting onto the *P. edulis* Guinezinho cultivar (12.86) and *P. cincinnata* (8.60 ± 2.44) species, higher by 55.68% and 132.79%, respectively. Under irrigation with water at 0.5 dS m⁻¹, the scions differed only when grafted onto *P. foetida*, and the scion of the Guinezinho cultivar showed a higher early ripening index (20.02), superior to those obtained with the BRS YG1 (4.41) and BRS SC1 (8.08 ± 1.77) cultivars, which were 353.97% and 147.77% higher, respectively (Figure 11A).

When under irrigation with 3.0 dS m⁻¹, the rootstocks differed only when combined with the scion of the BRS YG1 cultivar, and with *P. foetida* rootstock, the early ripening index was 8.02, superior to those obtained with the *P. edulis* rootstocks of the Guinezinho

cultivar (2.09) and *P. cincinnata* (2.84) by 283.73% and 182.39%, respectively. The scions only differed when grafted onto the Guinezinho cultivar of *P. edulis* and *P. cincinnata*, and when grafted onto the Guinezinho cultivar; the highest early maturation index value occurred with the Guinezinho cultivar (16.89) scion, followed by the BRS SC1 (6.20) and BRS YG1 (2.09) cultivars, with the value obtained with the Guinezinho cultivar being 172.42% and 708.13% higher, respectively.

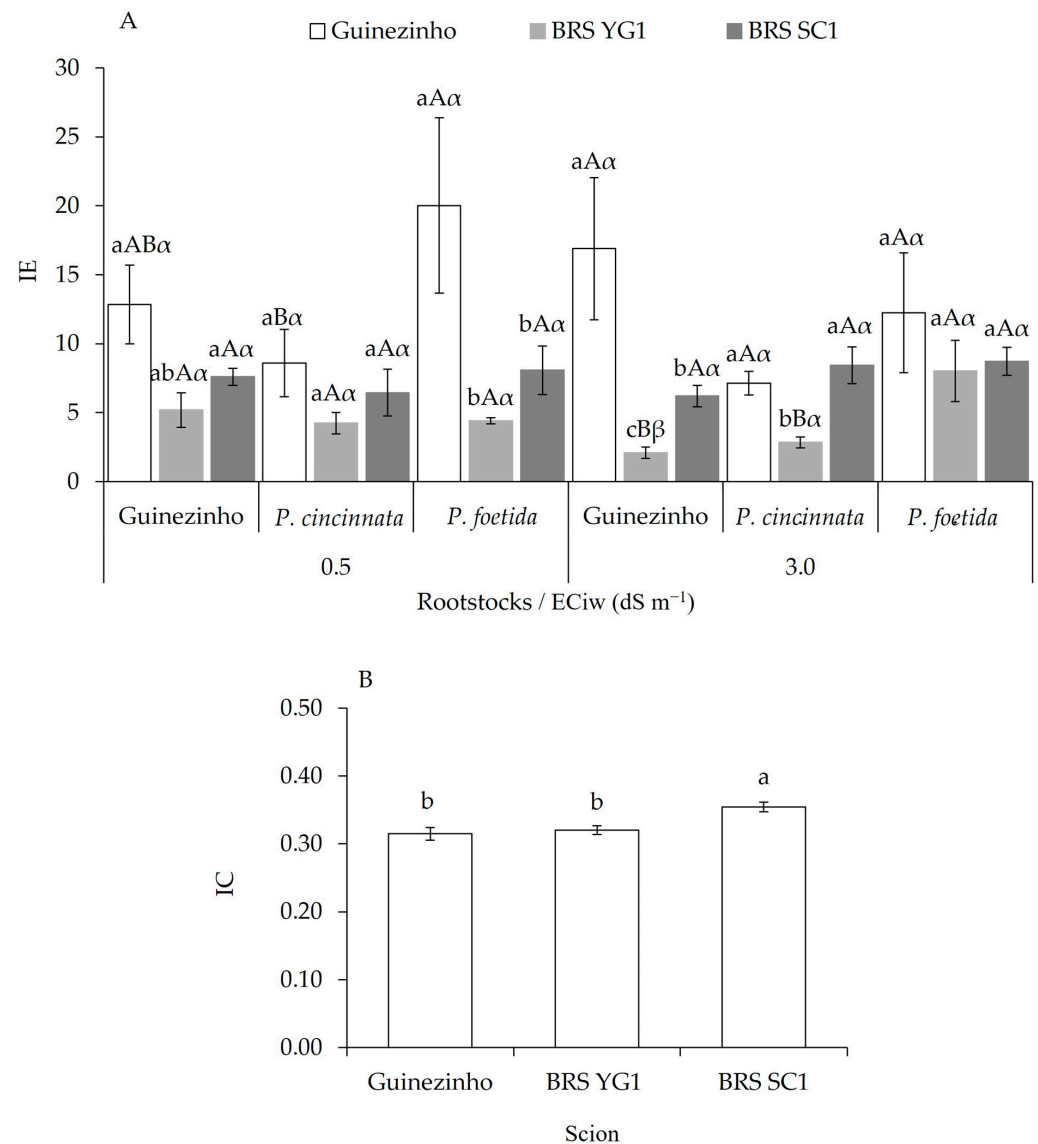


Figure 11. Mean values $\pm$ standard error of the mean early ripening index—ERI of yellow passion fruit orchard (A), in response to the electrical conductivity of irrigation water—ECiw (0.5 and 3.0 dS m⁻¹) of the *Passiflora* species used as rootstocks (Guinezinho, *P. cincinnata* and *P. foetida*), of the *P. edulis* cultivars used as scions (Guinezinho, BRS YG1 and BRS SC1), and of the concentrated crop index—CCI (B), in response to the *P. edulis* cultivars used as scions (Guinezinho, BRS YG1 and BRS SC1). Means followed by the same letter, lowercase between scions, uppercase between rootstocks, and Greek letters between irrigation water electrical conductivity, do not differ from each other by Tukey's test ($p \leq 0.05$).

The Guinezinho, BRS YG1, and BRS SC1 cultivars of *P. edulis*, when grafted and irrigated with water at 0.5 dS m⁻¹ and 3.0 dS m⁻¹, showed a greater increase in the early ripening index compared to the cultivars without grafting (Table 7). For the non-grafted *P. edulis* cultivars, differences were observed ($F = 14.29$; $p < 0.0001$; $CV_{\text{subplot}} = 56.15\%$), with

the highest average obtained with the Guinezinho cultivar (2.75), higher than the averages obtained with the BRS YG1 (0.25) and BRS SC1 (0.52) cultivars, which did not differ from each other. No effect of the electrical conductivity of the irrigation water was observed ($F = 0.11$; $p = 1.57$; $CV_{\text{plot}} = 63.79\%$).

In the concentrated crop index, only the scions showed an effect ($F = 4.97$; $p = 0.0098$, $CV = 25.59\%$). The scion of the BRS SC1 cultivar resulted in the highest concentrated crop index (0.35), 12.90% and 9.37% higher than the values obtained with the scions of the Guinezinho (0.31) and BRS YG1 (0.32) cultivars, respectively, and the values of Guinezinho and BRS YG1 did not differ from each other (Figure 11B). For non-grafted *P. edulis*, an interaction was observed between the cultivars and the electrical conductivity of the irrigation water ($F = 42.64$; $p < 0.0001$; $CV_{\text{plot}} = 39.56\%$; $CV_{\text{subplot}} = 26.60\%$). Under irrigation with water at 0.5 dS m^{-1} , the highest crop concentration index was obtained with the BRS SC1 cultivar (0.64), exceeding the values obtained with the Guinezinho (0.40) and BRS YG1 (0.47) cultivars, which did not differ from each other (Table 7). When irrigating with water at 3.0 dS m^{-1} , the three cultivars differed from each other, with estimated values of 0.80, 0.47, and 0.33 for the BRS YG1, SC1, and Guinezinho cultivars, respectively. When the electrical conductivity of the irrigation water was changed from 0.5 dS m^{-1} to 3.0 dS m^{-1} , for the concentration crop index, no difference was observed in the Guinezinho cultivar, while for the BRS YG1 cultivar, there was an increase of 70.2%, and for the BRS SC1 cultivar, there was a reduction of 26.6%.

3.4. Multivariate Analysis (Principal Component and Cluster Analyses) of Phenological, Growth, and Productive Traits of *Passiflora edulis* Under Saline Water Irrigation

In the principal component analysis, the phenological, growth, and productive variables of *P. edulis* under irrigation with non-saline (0.5 dS m^{-1}) and saline (3.0 dS m^{-1}) water, cultivated without grafting and with interspecific and intraspecific grafting, were summarized into three principal components, representing 76.65% of the total variation (Table 8).

The first principal component, accounting for 44.12% of the total variability, is related to the duration of the vegetative and productive phases and crop productivity (Table 8). The variables with the greatest contribution (eigenvector 2×100) in this component were the period for pruning the main stem (16.09%), productivity (15.14%), number of fruits (14.94%), duration of the productive phase (14.19%), and concentrated cultivation index (11.86%), with plants that reach the trellis in less time having a longer time in the productive phase, contributing to higher productivity distributed more homogeneously among the harvests.

The second component, accounting for 19.98% of the total variability, relates stem growth to the physical quality of the passion fruit, with the average fruit mass contributing 30.87% (eigenvector² $\times 100$) of the component, followed by the variables stem diameter at the end of the cycle (24.65%), absolute stem growth rate (11.41%), and stem diameter at the time of pruning the main stem (10.71%), indicating that the average mass of the passion fruit is directly related to stem diameter growth.

In the third principal component, representing 12.55% of the total variability, we observe the relationship between the production cycle, with 23.37% (eigenvector² $\times 100$) of the component, the formation phase of secondary and productive branches, with 21.08% of the component, and the number of productive branches, with 16.80% of the component. This reveals that shorter cycles had longer periods for the formation of secondary and productive branches, and a greater number of productive branches.

According to the cluster analysis, based on the treatment scores, two groups were formed (Figure 12). The first group includes grafted plants with all combinations of rootstocks and scions, in both electrical conductivities of irrigation water. In this group, it is observed that the highest productivity and the greatest number of fruits are related to the use of *P. foetida* as rootstock, and that using *P. edulis* as rootstock reduces production. In the

second group, the ungrafted plants reached the trellis faster and had more concentrated production, but had a lower yield.

Table 8. Matrix of eigenvalues and eigenvectors of the principal components (PCs) of phenological, growth, and production variables of *P. edulis* cultivars without grafting, with interspecific and intraspecific grafting, and with irrigation using non-saline and saline water.

	PC1	PC2	PC3
Eigenvalue (λ)	5.74	2.60	1.63
Explained variance (%)	44.12	19.98	12.55
Cumulative variance (%)	44.12	64.10	76.65
	Eigenvector ¹		
Period for pruning the main stem (PPMS)	−0.4011	0.0050	−0.1472
Formation of secondary and productive branches (PFSPB)	0.2224	−0.2521	0.4591
Productive phase Duration of the production phase (DPP)	0.3767	0.1445	−0.2389
Culture cycle (Cycle)	0.1782	−0.0140	−0.4834
Diameter at the time of pruning of the main stem (D_PHS)	−0.0971	0.3272	−0.1374
Diameter at the time of pruning at the end of cultivation (D_PEC)	−0.0127	0.4965	0.3453
Absolute growth rate in stem diameter (D_AGR)	−0.2324	0.3379	0.2847
Relative growth rate in stem diameter (D_RGR)	0.0000	0.0000	0.0000
Number of productive branches (NPB)	0.2047	−0.2010	0.4099
Early ripening index (ERI)	0.3017	0.2245	0.1968
Concentrated cultivation index (CCI)	−0.3444	−0.1591	0.2232
Number of fruits per plant (NF)	0.3865	−0.0420	−0.0114
Average fruit weight (AFW)	0.0022	0.5556	−0.0163
Yield	0.3891	0.1447	0.0263

¹ The criterion used to separate the representative variables of the component was based on values greater than the absolute value of the ratio $0.5(\lambda^{-0.5})$, highlighted in bold [43]. The percentage contribution of each variable to the component was calculated using the eigenvector 2×100 .

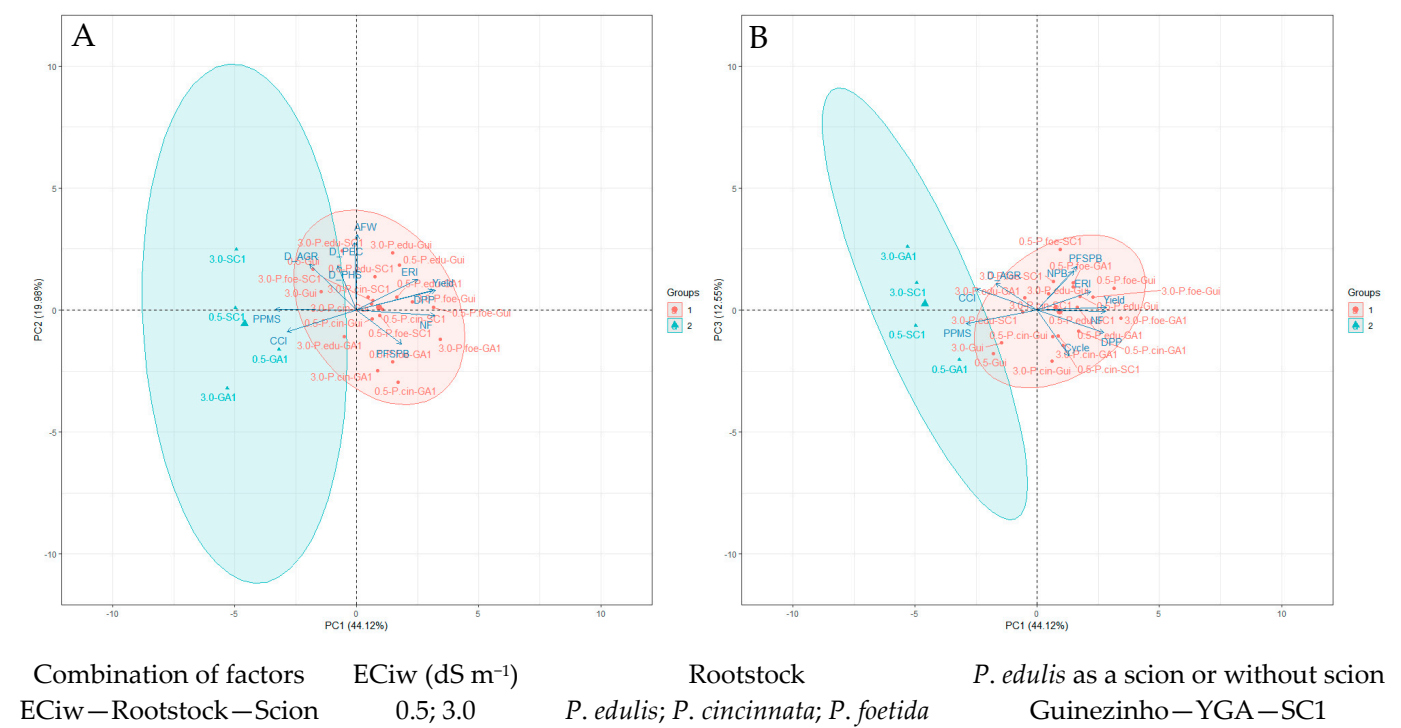


Figure 12. Dispersion of phenological, growth, and production variables of *P. edulis* and treatment arguments based on the scores of the first (PC1) and second (PC2) principal components (A), and the first (PC1) and third (PC3) principal components (B).

4. Discussion

4.1. Rootstock Influence on Development and Vegetative Growth

Regardless of the *P. edulis* cultivar used as scion, the use of *P. foetida* as rootstock reduced the period for pruning the main stem, possibly due to the rapid growth of this species [19]. This result reinforces the potential of *P. foetida* as a rootstock in production systems that prioritize earliness. Reference [25] states that the control of plant size and architecture is the most important effect of the rootstock on the canopy. According to these authors, hormonal interaction, movement of proteins and small molecules, absorption, and transport of nutrients are influenced by grafting, and these conditions control plant growth, development, and production.

The species *P. foetida* was subsequently sown to obtain rootstocks due to its faster growth compared to other species. This reduction in pruning time for the main stem is due to this faster growth characteristic, thus influencing the growth of the scion. As [24] states, grafting can alter the growth habits of both scions and rootstocks. *P. foetida* tolerates irrigation with water that has an electrical conductivity of 4.0 dS m^{-1} , showing good growth even under saline stress conditions [23]. In addition, grafting *P. edulis* onto *P. foetida* has been associated with improved vegetative growth under saline stress, highlighting the potential of this rootstock [13]. Thus, it can be considered a vigorous rootstock, as it maintained its growth even under saline water conditions and abiotic stress. According to [25], hormonal interaction is influenced by grafting, and these conditions control the growth, development, and production of the plant. Cytokinins are plant hormones primarily synthesized in the roots and transported via the xylem to the aerial parts, where they promote cell division, growth, and developmental regulation [44,45]. Possibly, *P. foetida* rootstocks produce a greater quantity of cytokinins, in addition to absorbing a greater amount of nutrients, which contributes to vegetative growth, since, according to [46], vigorous rootstocks increase the capacity for water and nutrient transport and vegetative growth.

The *P. foetida* species reduced the period for main stem pruning and contributed to a longer period for the formation of secondary and productive branches. In cultivation with grafted plants, this formation period was increased. The *P. foetida* rootstock also contributed to higher rates of early ripening, which represents the anticipation of productivity during the harvest period, and the higher the value of this index, the earlier the cultivation, that is, the faster the start of productivity and the quicker the economic return [1,39].

4.2. Stem Diameter and Scion Compatibility

The passion fruit species used as scion and rootstock differ in diameter. Plants with the yellow passion fruit (*P. edulis*) Guinezinho cultivar as rootstock showed a larger diameter compared to those using the wild *P. foetida* and *P. cincinnata* species as rootstock [47]. It was identified in seedlings after 100 days of transplanting that *P. edulis* plants had a larger diameter compared to the wild species *P. alata* and *P. ligularis*. The salinity of the irrigation water did not interfere with the diameter, while other studies identified damaging effects of saline water on passion fruit, with a smaller stem diameter under the use of water with higher electrical conductivity, as identified by [48] in *P. edulis* seedlings 105 days after transplanting, and there was lower biomass accumulation in seedlings under saline water [49].

At pruning time, non-grafted Guinezinho plants showed a larger diameter than grafted plants, but at the end of the cycle, only plants grafted with the BRS YG1 cultivar differed, with a larger diameter when grafted. The temporal dynamics of stem diameter reveal a scion establishment cost, as at pruning, non-grafted Guinezinho exhibited a larger diameter, suggesting initial resource allocation to scion union healing. However, by harvest end, grafted BRS YG1 surpassed non-grafted plants, indicating successful rootstock-

mediated vigor enhancement. This scion-specific response suggests genetic variability in scion compatibility. According to [24], grafting can alter the growth habits of both scions and rootstocks. Given this statement, it is understood that there is a mutual influence between rootstock and scion, where the response depends not only on the rootstock used, but also on the scion, that is, on the compatibility and interaction between the grafted species. Reference [50] states that compatible scions develop normally and exhibit functional connections between xylem and phloem, and a scion union capable of withstanding mechanical stress, while incompatible scions result in weak junctions and stunted scion growth. The rootstocks of the Guinezinho cultivar and *P. foetida* showed not only the largest diameter at the end of the growing cycle, but also the highest absolute and relative growth rates, which contributed to the larger diameters.

4.3. Production and Productivity

Based on the growth results, it is observed that the *P. foetida* rootstock is vigorous. Since the rootstock modifies nutrient transport [25], the *P. foetida* rootstock possibly contributed to greater nutrient absorption and consequent precocity in the ripening index, as also observed by [51] in grafted passion fruit. However, regarding the concentrated crop index, grafting reduced it, thus resulting in more distributed production, which means harvests with similar yields. According to [52], suitable rootstocks help to balance vegetative and reproductive growth, preventing premature exhaustion of the plant and allowing for longer and more stable production cycles.

The highest number of fruits was obtained with *P. foetida* rootstock grafted with the BRS YG1 cultivar, and the only interaction between rootstock and scion showed an increase in the number of fruits when irrigated with saline water. Rootstocks and scions of the Guinezinho cultivar did not result in a higher number of fruits, but in fruits with a higher average mass; however, the fruits of the Guinezinho cultivar have a thicker peel, so possibly a large part of the fruit weight can be attributed to the peel weight and not the pulp weight [53].

The relationship between rootstock and scion is important because not only the rootstock but also the scions that are used influence the number of fruits. The species *P. foetida* tolerates irrigation with saline water (4.0 dS m^{-1}) [23] with vigorous rootstock, as it maintains growth even under saline conditions. In addition, grafting *P. edulis* onto *P. foetida* has been associated with improved vegetative growth under saline stress [13], which may positively reflect on the productive capacity of the crop. It also contributed to a greater number of fruits when associated with the BRS YG1 cultivar scion, and fruit production was favored by increased salinity, a situation that did not occur when combined with other cultivars. Thus, the importance of not only the rootstock but also the scion is observed. This differs from what was observed by [1] with *P. edulis*, where a reduction in the number of fruits per plant occurred with increasing irrigation water salinity from 0.3 to 4.0 dS m^{-1} .

Regarding productivity [20], higher values were obtained for ungrafted *P. edulis* than when grafted onto *P. gibertii* [54], and we found no differences in yield between ungrafted and grafted *P. edulis* onto *P. gibertii* and *P. alata*. The Guinezinho cultivar grafted onto *P. cinccinata* in the studies by [55] resulted in lower productivity, as was found in the studies by [14,56] in a lower number of fruits compared to ungrafted plants. Unlike the results obtained by these authors, in the present study, grafting provided a greater number of fruits, higher production, and productivity. However, when using the Guinezinho cultivar scion, regardless of the rootstock, the number of fruits was not altered.

Regarding productivity, the yields observed in this study, ranging from 5.0 to 6.0 t ha^{-1} , even under non-saline irrigation, were lower than the national average yield of approximately 15 t ha^{-1} reported for Brazil, particularly in the northeast region [4]. However,

this difference is mainly explained by the shorter harvest period evaluated in this study. Harvests were conducted for only 153 days (approximately five months), whereas yellow passion fruit can be harvested for up to 18 months under commercial conditions [1,7]. Therefore, the yields reported here represent partial production. Despite the shorter evaluation period, grafting, particularly the combination of *P. foetida* rootstock with the BRS YG1 scion, resulted in a higher number of fruits, production, and productivity, highlighting the positive contribution of grafting to crop performance, even under saline irrigation.

The highest yields were obtained when using *P. foetida* rootstock in conjunction with the BRS YG1 cultivar scion. The influence of both the rootstock and the scion is observed, with these higher yields resulting from the compatibility between these species, as the same behavior was not observed with the other scions. *P. foetida* is a species that maintains its growth even under saline irrigation conditions [23], and in the present study, *P. foetida* as rootstock combined with *P. edulis* of the BRS Y1 cultivar showed increased production and productivity with increasing salinity of the irrigation water. *P. foetida* has been reported to exhibit greater tolerance to saline irrigation due to its capacity to reduce the accumulation of reactive oxygen species (ROS), particularly hydrogen peroxide, through increased synthesis and activity of antioxidant enzymes such as catalase [13]. In addition, studies with other *Passiflora* species indicate that grafting onto tolerant rootstocks, such as *P. cincinnata*, may contribute to restricting the absorption and transport of toxic ions, including Na^+ and Cl^- , under saline conditions [14]. Although ion accumulation and transport were not evaluated in the present study, similar mechanisms may partially contribute to the improved performance observed in *P. foetida*-grafted plants. Furthermore, previous reports indicate that some *Passiflora* species are capable of ion compartmentalization or salt excretion through the root system [15,16], which may help explain the higher fruit number, production, and productivity observed under saline irrigation. Taken together, these characteristics, along with other physiological and morphological traits not directly assessed in this study, likely contribute to the superior vigor and productive performance of *P. foetida* as a rootstock under saline conditions.

4.4. Hormonal and Physiological Aspects of Saline Water Tolerance

The root is the first plant organ directly exposed to hyperosmotic and toxic conditions in the rhizosphere; therefore, the ability of roots to adapt to adverse conditions is critical for the performance of the entire plant, with most changes to optimize plant performance under saline conditions mediated by modulation of the plant hormonal balance [3]. Cytokinins are plant hormones synthesized mainly in the roots and transported via the xylem to the aerial parts, where they promote cell division, growth, and developmental regulation [44,45]. In this context, the greater vegetative vigor and productive performance observed in plants grafted onto *P. foetida* may be partially interpreted in light of hormonal-mediated root–shoot signaling.

Ref. [57] reports that reduced cytokinin levels increase plant sensitivity to abscisic acid, resulting in decreased branch growth, while abscisic acid acts as a defense-related hormone, with growth reduction representing a survival strategy under saline stress. Several studies indicate that lower cytokinin levels are associated with increased tolerance to salinity, although often accompanied by reduced vegetative growth. In this context, considering the known functions of cytokinins in regulating plant growth, these hormonal interactions may contribute to the growth patterns observed in the present study, suggesting a shift in the balance between growth and stress defense [58]. Furthermore, the existence of reciprocal regulatory mechanisms between cytokinin and abscisic acid metabolism has been described, which may enable fine adjustment of plant responses to saline conditions

and help maintain physiological homeostasis under stress for maintenance of plant growth and development [59].

Cytokinin is essential in promoting cell division, growth, and plant development [60]. Currently, positive effects of increased cytokinin concentration in response to abiotic stresses are reported [17,18,61]. Although plant hormones were not quantified in the present study, evidence from other crops indicates that saline stress increased cytokinin content in tomatoes [17], and in maize, cytokinin signaling positively modulates tolerance to excess soluble salts; cytokinin promotes salt (NaCl) tolerance, promoting Cl^- exclusion in the aerial part, and cytokinin signaling promotes Cl^- homeostasis [17]. Another study using *Bacillus velezensis* HR6–1 inoculation promoted an increase in cytokinin content in tomato seedlings under saline stress, which was consistent with the high expression of several synthesis genes, implying that HR6-1 stimulated cytokinin synthesis to increase tomato resistance to saline stress. Tomatoes inoculated with HR6–1 exhibited better Na^+/K^+ balance and less accumulation of reactive oxygen species and oxidative damage, and higher antioxidant enzyme activities compared to non-colonized tomatoes under saline stress [62].

In rice mutants, increased branching and growth of the primary and secondary panicle was associated with increased levels of trans-zeatin, isopentenyladenine, kinetin, and dihydrozeatin in the inflorescence meristem, and with better tolerance to saline stress, showing less growth restriction, a greater number of panicles, higher levels of photosynthetic pigments and photosynthetic rates, better water content, and less oxidative damage determined by electrolyte leakage [63]. In genetically modified rice lines, increasing the level of the active form of cytokinin resulted in higher yields and plants with greater tolerance to stress caused by drought and salinity, maintaining efficient photosynthetic processes, minimizing yield loss, improving overall physiological performance, and maintaining redox balance, with the maintenance of a physiologically favorable K^+/Na^+ ratio, one of the main response strategies to ionic toxicity under severe saline stress [64].

Thus, in addition to the mechanism of restricting absorption and transport of toxic ions (Na^+ and Cl^-) from irrigation water, as reported by [14] in plants grafted onto *P. cinnamomata*, *P. foetida* may also involve physiological adjustments commonly associated with growth regulation under saline conditions, which could contribute to the greater growth and productivity observed in the BRS YG1 cultivar grafted onto this rootstock. According to [46], vigorous rootstocks increase the capacity for water and nutrient transport, which not only promotes vegetative development but also results in a consequent increase in productivity. However, given the different responses among the cultivars grafted onto *P. foetida*, it is understood that the interaction between rootstock and scion is of great importance in the responsiveness of the scion to the rootstock. Reference [19] identified the BRS YG1 cultivar as having high vigor, while *P. foetida* showed rapid growth. In the present study, the interaction proved to be compatible, with a mutual relationship between the BRS YG1 cultivar of the species *P. edulis*, as a scion, and the species *P. foetida*, as a rootstock.

4.5. Response of Ungrafted Cultivars to Saline Water

The ungrafted Guinezinho, BRS YG1, and BRS SC1 cultivars showed distinct behaviors regarding vegetative growth and productive aspects when subjected to irrigation with non-saline and saline water. The Guinezinho cultivar stood out for presenting better growth and higher yield, in addition to being more tolerant to irrigation with saline water compared to the BRS YG1 and BRS SC1 cultivars. The BRS YG1 cultivar had its growth and yield more compromised by excess salts in the irrigation water than the BRS SC1 cultivar; thus, BRS YG1 was more sensitive to salinity. Among the hybrids, BRS YG1 had the most compromised growth and productive components due to irrigation with saline water when compared to BRS SC1, evidencing greater sensitivity of the BRS YG1 cultivar to the salinity

of the irrigation water. This superiority of Guinezinho is probably associated with the genetic characteristics of the cultivar, with a higher degree of tolerance to saline water, since it is a material resulting from mass selection carried out over successive cultivation cycles in a semi-arid region and under irrigation with saline water.

Research by [65,66] identified that irrigation with saline water (3.4 dS m^{-1}) did not compromise the productive capacity of the Guinezinho cultivar, while [67,68] identified that irrigation with saline water (3.4 dS m^{-1}) compromised the productivity of the BRS YG1 cultivar. Thus, the results of the present study corroborate the findings in the literature and reinforce the greater tolerance of the Guinezinho cultivar to saline water, in contrast to the BRS YG1 and BRS SC1 hybrids, especially BRS YG1, which proved to be more sensitive to saline, but which had this characteristic altered when grafted onto *P. foetida*, resulting in better growth and yield, and increased productivity when under irrigation with saline water, the only rootstock and scion combination that was favored by irrigation with saline water.

5. Conclusions

The results of this study highlight that irrigation with saline water does not compromise the growth of grafted passion fruit plants, regardless of the rootstock and scion combinations used. However, the use of *P. foetida* rootstock promotes earlier pruning of the main stem of the passion fruit plant, indicating that this species favors plant growth. The use of saline water at 3.0 dS m^{-1} for irrigation only compromises the production of the BRS YG1 cultivar grafted onto the Guinezinho cultivar of *P. edulis*, characterizing this grafting as sensitive to salinity. The combination of *P. foetida* as rootstock and *P. edulis* cultivar BRS YG1 as scion shows the highest compatibility among the pairs evaluated. Furthermore, this combination is favored by the higher electrical conductivity of the irrigation water, indicating potential for use in saline conditions. Ungrafted cultivars of the *P. edulis* species differ from each other, but their potential is increased and modified when grafted. These findings indicate that grafting is an effective strategy to stimulate the growth, development, and productivity of yellow passion fruit, even under adverse salinity conditions. This approach significantly contributes to the sustainability and improvement of cultivation systems, especially in the face of the effects of climate change in regions with water containing high salt concentrations.

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Abbreviations

The following abbreviations are used in this manuscript:

ROS	Reactive oxygen species
pH	Potential of hydrogen
SB	Sum of bases
CEC	Cation exchange capacity
V	Base saturation
ESP	Exchangeable sodium percentage
OM	Organic matter
EC _{se}	Electrical conductivity of the soil saturation extract at 25 °C
SAR	Sodium adsorption ratio
WDC	Water-dispersible clay
D _f	Degree of flocculation
D _s	Density of soil
D _p	Density of particle
TP	Total porosity
EC	Electrical conductivity
ET _c	Crop evapotranspiration
ET _o	Reference evapotranspiration
kc	Coefficient in each phenophase
kr	Area reduction coefficient
PPMS	Period between transplanting and pruning the main stem
PFSPB	Period of formation of secondary and productive branches
PF	From beginning to the end of the harvest—the productive phase
CYCLE	From transplanting to the end of the harvest—crop cycle
NF	Number of fruits per plant
AFM	Average fruit mass
CY	Crop yield
ERI	Early ripening index
CCI	Concentrated crop index
F	F-test
CV	Coefficient of variation
BRS YG1	BRS Yellow Giant F1
BRS SC1	BRS Sun of Cerrado F1
EC _{iw}	Electrical conductivity of irrigation water
PCs	Principal components
DPP	Productive phase Duration of the production phase
D _{PHS}	Diameter at the time of pruning of the main stem
D _{PEC}	Diameter at the time of pruning at the end of cultivation
D _{AGR}	Absolute growth rate in stem diameter
D _{RGR}	Relative growth rate in stem diameter
NPB	Number of productive branches
(FW	Average fruit weight

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