Comunicata Scientiae
Horticultural Journal

ORIGINAL ARTICLE
published: 27 April 2023
https://doi.org/10.14295/CS.v14.3803

Quality of yellow passion fruit as a function of irrigation, artificial pollination, and protected cultivation

Nilciléia Mendes da Silva[1], Sebastião Elviro de Araújo Neto[1], Luís Gustavo de Souza e Souza[1]*, Geazí Penha Pinto[2], Regina Lucia Félix Ferreira[1], Thays Lemos Uchôa[1]

[1]Federal University of Acre, Rio Branco, Brazil
[2] Federal Institute of Acre, Rio Branco, Brazil
*Corresponding author, e-mail: gustavo_souza_fj@hotmail.com

Abstract

Passion fruit stands out among the fruit crops of economic expression in Brazil due to the medicinal, cosmetic, and organoleptic properties of its fruits, having great acceptance by consumers. In this scenario, this study aimed to evaluate the physical and chemical quality of organic yellow passion fruit as a function of pollination combined with irrigation and protected cultivation. The experimental design was in randomized blocks arranged in split plots (2 x 2 x 2), with eight treatments and four replications containing four plants per experimental unit. The protected environment was set up on the upper part of each espalier, consisting of a 100µ transparent plastic film used as cover. Irrigation was performed using a micro-sprinkler system, and pollination was either manual or natural (entomophilic). The following parameters were evaluated: soluble solids content; total titratable acidity; ratio of soluble solids to titratable acidity; gross pulp yield; and juice yield. Fruits were also classified according to their physical appearance by counting the number of fruits with slight, severe, or no damage, in addition to the equatorial fruit diameter. These assessments were carried out in two periods: crop season 1 (January to August 2019) and crop season 2 (September 2019 to August 2020). The results revealed that the cultivation system combining rainfed conditions, plastic protection of plants, and artificial pollination produced fruits with larger diameters and more class 5 fruits. Moreover, the cropping systems did not influence the gross pulp yield, juice yield, titratable acidity, soluble solids, and the ratio of soluble solids to titratable acidity.

Keywords: Fruit classification, organic farming, *Passiflora edulis* Sims.

Introduction

Brazil is the largest producer and consumer of yellow passion fruit in the world, with a total annual production of around 593,429 tons (IBGE, 2020). However, the passion fruit yield in the country (14.3 t ha^{-1}) is still low compared to the potential of this crop, which could surpass 52.7 t ha^{-1} (Jesus et al., 2018). Among the species cultivated in Brazil, yellow passion fruit (*Passiflora edulis* Sims) represents 90% of passion fruit growing areas used by the agroindustry and the fresh fruit market (Meletti, 2011).

Although Northern Brazil offers favorable edaphoclimatic conditions for passion fruit cultivation, the typical drought period in the southwest Amazon region, usually from May to September (Inmet, 2020), significantly limits passion fruit cultivation, mainly because this crop requires 86 mm of water month^{-1} during flowering and fruit setting (Dutra et al., 2018). This water deficit reduces passion fruit production under rainfed farming conditions (Silva et al., 2019; Uchôa et al., 2021b), after which plants might not be able to recover, thus compromising the following season (Galvão et al., 2020). Therefore, irrigation is used to reduce the effects of water deficit and increase crop yield (Cavalcante et al., 2020).

Even with organic management without insecticides, close to natural vegetation, and relying on a large population of *Xylocopa* spp. pollinating bees, low yields have still been observed for passion fruit (Araújo Neto et al., 2014; Galvão et al., 2020; Rezende et al., 2017; Silva, et al., 2019; Uchôa et al., 2018). From this perspective, artificial pollination becomes a necessary intervention, especially in areas with large populations of bees that damage flowers and/or steal pollen (Junqueira et al., 2013; Mascarello et al., 2019). Furthermore, artificial pollination provides more pollen than insect pollination (Barrera Júnior et al., 2020; Lage et al., 2018).

According to Koetz et al. (2010), protected

Received: 30 August 2021
Accepted: 07 February 2022

cultivation represents a potential alternative for passion fruit production for anticipating harvest and producing fruits with less physical damage, in addition to protecting plants from direct solar radiation and excessive rainfall. This protection improves the integrity of pollen grains, increasing fertilization and fruit production (Barrera Júnior et al., 2020; Martarello et al., 2021).

Therefore, since studies on this issue are extremely relevant, this study aimed to evaluate the physical and chemical quality of yellow passion fruit grown under organic conditions as a function of pollination, irrigation, and protected cultivation.

Material and Methods

The experiment was conducted at the Seridó Ecological Station in Rio Branco, Acre, Brazil, located at the coordinates 9° 53' 16'' S and 67° 49' 11'' W, at an elevation of 170 m above sea level. Seedling formation occurred from June to September 2018, and the seedlings were conducted from September 2018 to August 2020. The soil in the experimental area was classified as a Lithic YELLOW ULTISOL, with a slightly undulating topography without apparent erosion and with moderate drainage (Santos et al., 2013a).

The climate is hot, humid, and classified as Am according to the Köppen classification, with mean annual temperatures around 24.5 °C, relative air humidity of 84%, and annual rainfall ranging from 1,700 mm to 2,400 mm (Inmet, 2020).

Table 1. Soil analysis of the planting area in the Seridó Ecological Station at 0-20 cm depth, 2016.

	$g.dm^3$	$mg.dm^3$	--------------------------------			$mmolc.dm^3$		--------------------------------			%
pH	O.M.	P	K	Ca	Mg	Al	H	H+Al	SB	CEC	V
6.3	17	1.0	1.1	24	11	2	23	25	36.1	67.1	53.8

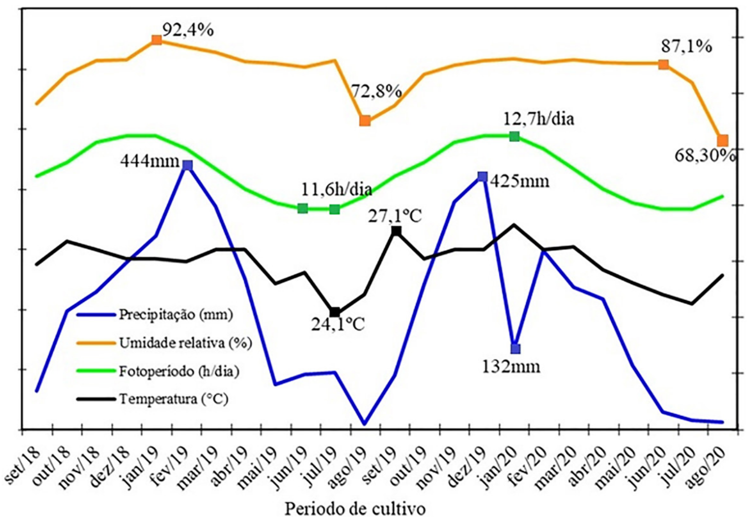

Figure 1. Mean rainfall (mm), relative air humidity (%), temperature (°C) and photoperiod (h/day), during the experimental period in Rio Branco, AC, from 2018 to 2020.

The experimental design was in randomized blocks arranged in split plots (2 x 2 x 2) with eight treatments and four replications, totaling four plants per experimental unit. The plot was formed by irrigation or rainfed farming, in which the other two factors were distributed: protected cultivation or direct sunlight exposure and artificial or natural pollination.

The passion fruit cultivar used in the experiment was a public domain synthetic F4 variety formed by genotypes 2, 22, 23, 35, 37, 33, and 20 from Viçosa (MG, Brazil), from the State University of Northern Rio de Janeiro (Campo dos Goytacazes, RJ, Brazil), and from the municipalities of Brasiléia and Rio Branco (AC, Brazil) (Negreiros et al., 2008).

Seedling formation occurred in a plant nursery from May to September 2018. Sowing was performed in 200-cell polystyrene trays, after which the seedlings were transferred to 3-L plastic bags containing substrate with the following composition: 33% soil, 33% organic compost, 33% ouricuri palm stem fiber (*Attalea phalerata*), 1.0 kg m^{-3} of dolomitic limestone, 1.5 kg m^{-3} of thermophosphate, and 1.0 kg m^{-3} of potassium sulfate, as recommended by Silva et al. (2018).

The seedlings were conducted in a plant nursery covered with a transparent 100-μ film, receiving irrigation twice a day to maintain the substrate close to field capacity until the seedlings reached 1.5 m in height and had a mean diameter of 4.76 mm, when they were transplanted to the field in September 2018. In their definitive location, the seedlings were spaced 2.5 m between rows and 3.0 m between plants and were evaluated until August 2020.

Planting holes 80 cm wide and 30 cm deep were opened after the area was cleaned with a motorized backpack brush cutter and fertilized with 20 L of organic compost (various naturally decomposed plant species without animal residues), 500 g of limestone, and 200 g of thermophosphate.

The plants were trained to a vertical shoot-positioned system using smooth wire No. 12 at the height of 2 m, attached and stretched with concrete columns spaced six meters.

The protected environment was set up above the vertical shoot-positioned system using a transparent 100-μ film cover supported by a wooden structure (Figure 2A), and irrigation was provided by a micro-sprinkler system (Figure 2B).

Figure 2. Conduction of the experimental planting of yellow passion fruit. A) Transparent 100-μ plastic film cover; B) Micro-sprinkler irrigation system; C) Manual passion fruit pollination. Picture: Nilciléia Mendes da Silva (2019).

The irrigation system was set up in the planting row using one micro-sprinkler per plant at a flow rate of 67.5 L h^{-1}. The moment of irrigation was determined by the soil water matric potential, measured with tensiometers installed at 0.15 m from the plant and 0.20 m deep into the soil. When the value was close to 60 kPa, it signaled the moment when water should be provided to the crop (Dutra et al., 2018). The readings were performed daily using a tensimeter.

Artificial pollination was performed daily with naked fingers between 1:00 p.m. and 5:00 p.m. Both before and during pollination, the anthers of the pollinated plants were collected so that the operators could touch their fingertips containing pollen on the surface of the stigmas from bottom to top (Figure 2C).

Topdressing fertilization was performed during crop formation and was split into two applications. Thermophosphate was the phosphorus source, whereas potassium sulfate was the potassium source. The first application was performed 60 days after planting using 176.5 g of P_2O_5 $plant^{-1}$ and 88.2 g of K_2SO_4 $plant^{-1}$. The second application was performed 120 days after planting using 176.5 g of P_2O_5 $plant^{-1}$ and 88.2 g of K_2SO_4 $plant^{-1}$.

All management practices were performed according to the ecological management proposed by Araújo Neto & Ferreira (2019), Rezende et al. (2017), Silva et al. (2019), Uchôa et al. (2021b), and by MAPA Normative Instructions No. 46 of 2011 and No. 17 of 2014. In addition, the Bordeaux and lime sulfur mixtures were used to protect the plants against pathogens and pests.

Passion fruit harvest was performed two or three times a week by collecting fallen fruits and ripe fruits on the plants. The fruits were considered ripe when 55% of their peel was yellow, indicating a point when fruit quality is maintained and shelf life is increased during storage (Santos et al., 2013b).

Passion fruit quality was determined using ten ripe fruits from each plot, which were evaluated for soluble solids (SS), total titratable acidity (TA), ratio of soluble solids to titratable acidity (SS/TA), gross pulp yield (RPB), and juice yield (RS). These evaluations were performed in two periods: June 2019 and February 2020.

Acidity was determined by titration using 1 mL of passion fruit juice diluted in 49 mL of distilled water, followed by sodium hydroxide titration (NaOH) at 0.1 N using 1% phenolphthalein as an indicator, with results expressed as percentage of citric acid. The soluble solids were measured using a digital refractometer with automatic temperature control, with results expressed as °Brix (Aoac, 2012). The ratio of soluble solids to titratable acidity was obtained by the quotient between the percent contents of SS and TA.

To determine the gross pulp yield (RPB), the whole fruits were first weighed on a precision balance and then cut to remove and weigh the gross pulp content (juice + aril + seeds). The RPB was determined as the ratio of gross pulp mass to fruit mass, subsequently converted to percentage.

After measuring the fruit mass and the gross pulp mass, the pulp was processed in an electric mixer and sieved to separate the seeds, thus obtaining the quotient between juice mass and fruit mass, subsequently converted to percent juice yield.

The physical attributes were measured using 50 fruits from each plot. The evaluations were performed in crop seasons 1 (June 2019) and 2 (February 2020).

The physical appearance was analyzed to classify the fruits into different categories referring to fruits with slight, severe, or no damage according to the current rules for the standardization, identity, and quality (PIQ) of yellow passion fruit in Brazil (Brasil, 2000).

Fruit classification was performed during harvest by analyzing 50 random fruit samples from each experimental plot. The external fruit appearance was analyzed based on the criteria established by the Brazilian program for the improvement of commercial and packaging standards of horticultural products (Table 2). nce of severe and slight damage in passion fruit

Table 2. Categories determined by the occurrence of severe and slight damage in passion fruit.

Type of damage	Category				
	Extra	I	II	III	Organic
Unripe	0%	2%	3%	20%	20%
Deep damage	0%	1%	3%	20%	20%
Rotting	0%	1%	3%	8%	8%
Total severe	0%	3%	7%	100%	100%
Total slight	5%	10%	25%	100%	100%
Overall total	5%	10%	25%	100%	100%

Source: (Brasil, 2000; Francisco et al., 2020).

According to the conventional classification, fruits with a few deformities in the epidermis but a fully preserved interior belonged to category II, meaning fruits with little use and classified as organic. Due to the particularities of organic foods, which are usually only aesthetically compromised and have no classification of their own, the "organic" category was idealized in this study. Therefore, the fruits were classified as Extra – fruits with a maximum of 5% of slight damage; and Organic – fruits with up to 100% damage (with a fully preserved endocarp), also admitting up to 20% of severe damage.

This logic follows one of the principles of organic agriculture, which is valuing the internal quality and the absence of toxic residues in food (Araújo Neto & Ferreira, 2019).

Fruit size was measured based on the equatorial fruit diameter using a digital caliper, after which the fruits were separated according to their class, ranging from 1 to 5 (Table 3). The sampling used for commercial classification was the same used for physical evaluation and performed during the same period using 50 fruits per plot and 200 fruits for each mean.

Table 3. Passion fruit characterization with regard to fruit size.

Class	Equatorial Diameter (mm)
1	Equal to or lower than 55
2	Equal to or greater than 55 up to 65
3	Equal to or greater than 65 up to 75
4	Equal to or greater than 75 up to 85
5	Greater than 85

Source: (Brasil, 2000; Francisco et al., 2020)

The statistical analysis was performed by checking for outliers, normality of errors by the Shapiro-Wilk test, and homogeneity of variances by the Bartlett test. The analysis of variance was subsequently performed. Whenever the F-value indicated a difference between qualitative treatments ($p<0.05$), the Tukey test was applied at the level of 5% probability.

Results and Dicussion

The yield of the pulp with seeds and the juice yield were not influenced by the cultivation factors evaluated in the two crop seasons (Table 4).

Although there was no significant difference between treatments ($p>0.05$) in the two crop seasons, the mean juice yield (36.3 to 37.5 %) and the gross pulp yield (40.6 to 40.7%) of yellow passion fruit evaluated in the present study met the Brazilian quality standards (Brazil, 2000). Fresh passion fruit commercialization requires fruits with pulp yields around 36%, a yellow-gold juice color, and soluble solids contents above 13 °Brix (Dias et al., 2007).

The evaluated factors (irrigation x pollination x cover) had a triple interaction on the equatorial fruit diameter during crop season 1 (Table 5).

Table 4. Gross pulp yield (RPB) and juice yield (RS) of organic yellow passion fruit under different cropping systems in two crop seasons. Seridó Ecological Station, Rio Branco – Acre, Brazil.

Treatments	Crop Season 1 (Jan.-Aug. 2019)^{ns}		Crop Season 2 (Sep. 2019 to Aug. 2020)^{ns}	
	RPB	RS	RPB	RS
Irrigated, covered, and artificial pollination	40.9	36.4	40.9	37.6
Irrigated, full sunlight, and artificial pollination	38.3	34.4	42.9	39.4
Irrigated, covered, and natural pollination	38.2	34.2	39.7	36.7
Irrigated, full sunlight, and natural pollination	45.1	40.4	39.8	36.8
Rainfed, covered, and artificial pollination	45.2	40.8	38.1	35.3
Rainfed, full sunlight, and artificial pollination	41.1	36.7	43.7	40.2
Rainfed, covered, and natural pollination	39.4	34.9	41.7	38.4
Rainfed, full sunlight, and natural pollination	36.4	32.5	38.3	35.5
Mean	40.6	36.3	40.7	37.5
C.V (%)	13.8	13.7	12.2	11.7

^{ns} = non-significant (p>0.05)

Table 5. Diameter of organic yellow passion fruit grown in different cropping systems in the first crop season. Seridó Ecological Station, Rio Branco – Acre, Brazil.

Mean fruit diameter (mm) Crop season 1				
Pollination	Irrigation		Rainfed	
	Protected cultivation	Full sunlight	Protected cultivation	Full sunlight
Artificial	69.75Baα	72.25Aaα	74.50Aaα	68.75Bbα
Natural	68.00Aaα	70.00Aaα	69.75Aaβ	71.00Baα

Different uppercase letters between rows for the irrigation factor. Different lowercase letters differ mean values for the plant cover effect in the column. Different Greek letters differ mean values between artificial and natural pollination.

In crop season 1, the plants conducted under rainfed conditions, plastic cover, and artificial pollination produced fruits with larger (p<0.05) diameters (74.5 mm) (Table 5). The number of fruits per plant is usually lower under these conditions (Silva et al., 2021), resulting in better photoassimilate partitioning for fruits and thus increasing the longitudinal fruit diameter when using this cropping system (Dias et al., 2017).

The fruit diameters obtained allow classifying these fruits in category 3, meaning fruits with diameters ranging from 65 mm to 75 mm. The larger the size of the fruit, the higher its marketing price since consumers consider fruit appearance as the primary purchase requirement (Dias et al., 2017).

Plants conducted with supplementary irrigation, under full sunlight exposure, and with artificial pollination showed larger fruit diameters (72.25mm) (p<0.05) than those grown under rainfed farming conditions (Table 5). According to Cavalcante et al. (2020), adequate water availability to this crop results in fruits with greater biomass. From this perspective, passion fruit plants require 5.8 mm of water day^{-1}, a demand that increases by 0.6 during vegetative growth and by up to 1.25 during flowering and fruit setting (Carr, 2013).

Furthermore, artificial pollination provides a larger amount of pollen than what insects provide, resulting in a higher number of fertilized eggs and, therefore, more seeds (Barrera Júnior et al., 2020; Fischer et al., 2018; Lage et al., 2018; Silveira et al., 2012). Consequently, these events result in greater fruit biomass, diameter, and length (Krause et al., 2012).

In crop season 2, the equatorial fruit diameter was influenced by the double interaction (p<0.05) between irrigation and protected environments (Table 6).

Table 6. Diameter of organic yellow passion fruit grown under different cropping systems in the second crop season. Seridó Ecological Station, Rio Branco – Acre, Brazil.

Mean fruit diameter (mm) Crop season 2		
Cover	Irrigation	Rainfed
Protected environment	72.63Ba	75.13Aa
Full sunlight exposure	73.38Aa	71.75Ab

Different lowercase letters differ (p<0.05) for the plant cover effect. Different uppercase letters differ (p<0.05) for the irrigation effect.

The plants grown under plastic protection and rainfed conditions produced fruits with larger diameters (p<0.05) in the second crop season (Table 6). These fruits are classified as class 4, in which the equatorial diameter ranges from 75 mm to 85 mm. Similar results were found by Dias et al. (2017) with passion fruit fertilized with nitrogen and potassium in northern Minas Gerais, with fruit diameters ranging from 70 mm to 79 mm.

Although the plants did not receive complementary irrigation during the drought period, the adequate water availability provided by rainfall (Figure 1) while the experiment was conducted might have provided better conditions for the photosynthetic metabolism, which, allied to protected cultivation, resulted in larger fruit diameters. According to Uchôa et al. (2021b), rainfed cultivation also produced higher percentages of extra fruits and fruits with diameter classes D1, D3, and D4, although without statistical significance due to the high coefficient of variation, which is typical for passion fruit. The authors also observed fewer fruits per plant, resulting in larger fruit sizes.

Table 7. Percentage of organic yellow passion fruit classified according to the category/class as a function of different cropping systems. Seridó Ecological Station, Rio Branco – Acre, Brazil.

TRAT	Crop Season 1					Crop Season 2				
	Class 1	Class 2	Class 3	Class 4	Class 5	Class 1	Class 2	Class 3	Class 4	Class 5
1	3.5	24.9	45.6	22.8	3.0	0.9	11.0	45.7	38.4	4.0
2	3.1	30.3	46.7	16.5	3.5	1.5	17.3	41.5	27.8	12.1
3	1.0	15.0	44.8	33.8	5.5	1.0	16.5	38.5	37.5	6.5
4	1.0	24.0	49.3	23.2	2.5	0.0	6.5	42.0	45.5	6.0
5	0.0	10.0	42.0	36.0	12.0	0.0	5.6	35.2	43.7	15.6
6	2.0	18.5	49.0	28.5	2.0	0.5	12.5	38.0	39.5	9.5
7	1.9	25.8	48.6	20.7	3.0	2.0	16.0	47.0	26.5	8.5
8	0.0	18.5	50.5	27.5	3.5	0.5	17.1	43.2	36.2	3.0
Mean	1.5	20.9	47.1	26.1	4.4	0.8	12.8	41.4	36.9	8.1

Treatments 1: irrigated, covered, and artificial pollination; 2: irrigated, covered, and natural pollination; 3: irrigated, full sunlight, and artificial pollination; 4: irrigated, full sunlight, and natural pollination; 5: rainfed, covered, artificial pollination; 6: rainfed, covered, natural pollination; 7: rainfed, full sunlight, and artificial pollination; 8: rainfed, full sunlight, and natural pollination.

Most fruits were concentrated in classes 3 and 4 (Table 7), with equatorial diameters ranging from 65 mm to 85 mm. Approximately 60% of passion fruit production is used for the fresh fruit market, which prefers large and oval-shaped fruits, whereas the remainder is used by the agroindustry (Meletti, 2011). According to Vianna-Silva et al. (2008), fruits with equatorial diameters ranging from 76 mm to 86 mm showed juice yield values around 40%, similar to those of the present study (Table 2).

It should be noted that there were fruits included in all categories. Carr (2013) explained this heterogeneity in production and stressed that temperature and water stress are the factors that most contribute to uneven production and fruit size during production.

There was a triple interaction for the fruits classified in class 5 (>85 mm) in crop season 1 (Table 8).

Table 8. Percentage of organic yellow passion fruit classified according to diameter as class 5 as a function of irrigation, pollination, and protected cultivation in crop season 1. Seridó Ecological Station, Rio Branco – Acre, Brazil.

Class 5 fruits (%) Crop season 1				
Cover	Artificial pollination		Natural pollination	
	Irrigated	Rainfed	Irrigated	Rainfed
Protected cultivation	3.2Baa	12.0Aaa	3.5Aaa	2.0Aaβ
Full sunlight exposure	5.5Aaa	3.0Aba	2.5Aaa	3.5Aaa

Different uppercase letters between rows for irrigation. Different lowercase letters differ mean values for the plant cover effect in the column. Different Greek letters differ mean values between artificial and natural pollination.

In crop season 1, the plants conducted under the plastic cover, with artificial pollination, and under rainfed conditions produced more class 5 fruits than the remaining cropping systems (Table 8). This proportion (12%) could be related to artificial pollination since, along with plant cover, this management favors larger fruit diameters (Table 8).

The 100 μ transparent plastic film cover maintained the pollen deposited on the flower stigmas. According to Lage et al. (2018), climatic factors such as relative air humidity and temperature can influence grain pollen viability. Furthermore, the solar protection provided by the film may have favored net photosynthesis and the accumulation of substances transported to the fruits (Koetz et al., 2010).

The percentages of fruits with slight and severe damage did not differ significantly ($p>0.05$) between treatments in the two crop seasons (Table 9).

Approximately 70% of fruits showed slight damage in the two crop seasons, whereas 2% to 7% showed severe damage in crop seasons 1 and 2, respectively (Table 9). External damage usually does not compromise the product, causing only superficial damage to the fruit epidermis, healed lesions, wrinkles, and spots or deformations. In contrast, severe damage includes rotting, deep lesions, or immature fruits, thus preventing commercialization (Brazil, 2000).

For Dias et al. (2017), the external fruit appearance is a very important qualitative attribute while purchasing the product since it is one of the main criteria for decision-making and for establishing prices. However, according to Araújo & Ferreira (2019), the consumers of organic products value much more the internal quality and absence of toxic residues than the external appearance.

On the other hand, the factors that most determine fruit quality during cultivation are the genetic characteristics of the variety, the environmental conditions, the later interaction between genotype and environment, and the crop management strategies (Fischer et al., 2018).

The higher percentage of flawless fruits in the first crop season was significantly influenced by the triple interaction between irrigation x cover x pollination (Table 10).

Table 9. Percentage of fruits with severe and slight damage among organic yellow passion fruit grown under different cropping systems in the two crop seasons. Seridó Ecological Station, Rio Branco – Acre, Brazil.

Treatments	Crop Season 1 ns		Crop Season 2 ns	
	Severe damage	Slight damage	Severe damage	Slight damage
Irrigated, covered, and artificial pollination	4.7	60.1	10.0	57.3
Irrigated, full sunlight, and artificial pollination	2.3	86.6	7.1	67.7
Irrigated, covered, and natural pollination	2.4	66.9	7.9	60.2
Irrigated, full sunlight, and natural pollination	2.4	82.1	6.1	77.5
Rainfed, covered, and artificial pollination	3.6	59.4	8.2	75.7
Rainfed, full sunlight, and artificial pollination	2.5	68.0	0.5	73.6
Rainfed, covered, and natural pollination	1.8	64.4	10.0	64.1
Rainfed, full sunlight, and natural pollination	1.4	79.8	10.0	75.3
Mean (%)	2.6	70.9	7.3	68.9
C.V (%)	113.9	14.8	53.9	14.7

ns = non-significant (p>0.05).

Table 10. Percentage of flawless fruits as a function of irrigation, pollination, and protected cultivation in crop season 1 (2019). Seridó Ecological Station, Rio Branco – Acre, Brazil.

Flawless fruits (%) Crop season 1					
Cover	Artificial pollination		Natural pollination		Mean
	Irrigation	Rainfed	Irrigation	Rainfed	
Protected cultivation	34.8Aaα	32.8Aaα	30.8Aaα	34.4Aaα	33.19 a
Full sunlight exposure	11.1Bbα	29.9Aaα	15.5Abα	19.3Abβ	18.95 b

Different uppercase letters between rows for irrigation. Different lowercase letters differ mean values for the plant cover effect in the column. Different Greek letters differ mean values between artificial and natural pollination.

Plant cover provided the highest percentage of flawless fruits, except under rainfed farming associated with artificial pollination (Table 10).

As observed in Tables 9 and 10, the plastic cover provided the highest percentage of flawless fruits in relation to the plants grown under full sunlight exposure in the two crop seasons. Confirming these results, Koetz et al. (2010) observed that cultivation in protected environments is a viable alternative to produce fruits with better appearance, i.e., less physical damage in relation to cultivation in natural environments.

In the second crop season, protected cultivation and natural pollination provided the highest percentage of flawless fruits (Table 11).

Table 11. Percentage of flawless fruits in the second crop season as a function of pollination and protected cultivation. Seridó Ecological Station, Rio Branco – Acre, Brazil.

Flawless fruits (%) Crop season 2		
Cover	Artificial pollination	Natural pollination
Protected environment	24.4Aa	28.8Aa
Full sunlight exposure	25.9Aa	16.1Bb

Different uppercase letters differ (p<0.05) for the plant cover effect in the column. Different lowercase letters differ for the artificial and/or natural pollination effect.

Pollination and protected cultivation had a significant interaction on the percentage of fruits with slight damage in the first season, and protected cultivation had significant effects on the percentage of fruits with slight damage and rotten fruits in the second crop season (Table 12).

Table 12. Percentage of fruits with slight damage and rotting in the two crop seasons as a function of protected cultivation and pollination. Seridó Ecological Station, Rio Branco – Acre, Brazil.

	Crop Season 1 (2019)	Crop Season 2 (2019/2020)	
	Slight Damage (%)	Slight Damage (%)	Rotting (%)
Artificial pollination	67.7 b	-	-
Natural pollination	75.7 a	-	-
Protected cultivation	65.1 b	64.3 b	7.4 a
Full sunlight exposure	78.3 a	73.5 a	3.1 b

Different lowercase letters in the column differ (p<0.05) by the Tukey test.

Cultivation under full sunlight exposure provided the highest percentage of fruits with slight damage in the two crop seasons, although with a lower percentage of rotten fruits in the second season (Table 12). In addition, spot formation was very common since the fruits were exposed to full sunlight. On the other hand, plant cover and favorable meteorological conditions favored the formation of a microclimate (high moisture and temperature), providing ideal conditions for the development of the anthracnose pathogen

(*Colletotrichum gloeosporioides*), the main factor contributing to fruit rot.

Passion fruit cultivation in the protected environment maintained the productivity and reduced the incidence of slight damage ($p<0.05$) in relation to cultivation under full sunlight exposure (Table 12), also resulting in a higher percentage of fruits classified as extra, i.e., flawless.

The evaluated factors did not affect the SS, TA, and SS/TA ratio in the two crop seasons (Table 13). It is common for these quality indicators to remain unchanged with organic crop management (Francisco et al., 2020; Rezende et al., 2017; Silva et al. 2019; Uchôa et al. 2018, 2021b).

Table 13. Titratable acidity (%), soluble solids (%), and ratio of soluble solids to titratable acidity (SS/TA) of yellow passion fruit grown under different cropping systems. Seridó Ecological Station, Rio Branco – Acre, Brazil.

Treatments	Crop season 1 (2019)^{ns}			Crop season 2 (2020)^{ns}		
	Titratable acidity (%)	Soluble solids (%)	Ratio (SS/TA)	Titratable acidity (%)	Soluble solids (%)	Ratio (SS/TA)
1	4.1	16.6	4.2	3.7	15.2	4.1
2	4.0	16.5	4.4	4.1	15.5	3.9
3	4.0	16.9	4.4	3.7	15.4	4.3
4	3.8	16.1	4.4	4.2	16.0	3.7
5	3.8	16.2	4.5	3.7	15.5	4.2
6	4.1	16.3	4.1	4.2	16.1	4.0
7	3.9	16.3	4.5	4.4	15.8	3.7
8	3.7	16.4	4.5	4.0	15.7	4.0
Mean	3.9	16.4	4.4	3.9	15.6	4.0

Treatments 1: irrigated, covered, and artificial pollination; 2: rainfed, covered, and artificial pollination; 3: irrigated, full sunlight, and artificial pollination; 4: rainfed, full sunlight, artificial pollination; 5: irrigated, covered, and natural pollination; 6: rainfed, covered, and natural pollination; 7: irrigated, full sunlight, and natural pollination; 8: rainfed, full sunlight, natural pollination.

The contents of titratable acidity and soluble solids in the two crop seasons remained above the respective minimum values of 2.5% and 11% established by the quality standards (Brasil, 2000).

In the two seasons, the mean titratable acidity was 3.9% (Table 13). This variable varies according to the maturity stage and harvest time (Vianna-Silva et al., 2008). However, the treatments did not cause significant chemical changes in the fruits even when evaluating different seasons in the present study.

In the processing industry, fruits are required to have high acidity contents, which improves nutritional and organoleptic properties and the food safety of products by reducing the volume of artificial acidifiers added to the juice (Abreu et al., 2009). In contrast, consumers prefer fresh fruits with higher SS contents and lower TA (Figueiredo et al., 2015), although acid fruits are preferably consumed after processing and with sugar.

The soluble solids are above the standards required for passion fruit, with a mean value of 16.4 °Brix in crop season 1 and 15.6 °Brix in season 2 (Table 13). This factor is important for the industrial fruit yield since the higher the SS concentration, the lower the number of fruits required to obtain the pulp for concentrated juices. According to Nascimento et al. (2003), 11 kg of fruits with TSS between 11 and 12 °Brix are required to obtain 1 kg of concentrated juice at 50 °Brix.

The mean values of the SS/TA ratio ranged from 4.4 to 4.0 in crop seasons 1 and 2, respectively (Table 10).

The SS/TA ratio is the ratio of soluble solids to total acidity, and this variable is entirely related to the contents of sugars and acids in the fruit. Therefore, this indicator is considered one of the more practical ways to evaluate juice flavor since it indicates both palatability and taste (Nascimento et al., 1998), especially in fresh fruits.

Conclusions

The cropping system consisting of rainfed farming, plastic protection, and artificial pollination produced fruits with larger diameters and more class 5 fruits. The number of fruits per plant was lower under rainfed conditions and pollination, which might increase fruit diameter.

Irrigation and artificial pollination increased fruit diameter under full sunlight exposure conditions.

Protected cultivation increased the production of flawless fruits in the two seasons.

The gross pulp yield, juice yield, titratable acidity, soluble solids, and SS/TA ratio of organic passion fruit were not influenced by pollination, irrigation, and protected environments. Moreover, these variables were within the values established by the Brazilian quality indices.

References

Abreu, S.P.M., Peixoto, J.R., Junqueira, N.T.V., Souza, M.A.F. 2009. Característica físico-químicas de cinco genótipos de maracujazeiro-azedo cultivados no Distrito Federal. *Revista Brasileira de Fruticultura* 31: 487-491.

Araújo Neto, S.E., Campos, P.A., Tavella, L.B., Solino, A.J.S., Silva, I.F. 2014. Organic polyculture of passion fruit, pineapple, corn and cassava: the influence of green manure and distance between espaliers. *Ciência e Agrotecnologia* 38: 247-255.

Araújo Neto, S.E., Ferreira, R.L.F. 2019. *Agricultura* *ecológica tropical*. Clube do autores, Joinville, Brasil, 169 p.

Barrera Júnior, W.B., Trinidad, K.A.D., Presas, J.A. 2020. Hand pollination and natural pollination by carpenter bees (*Xylocopa* spp.) in *Passiflora edulis* Sims. f. *flavicarpa* Deg. (yellow passion fruit). *Journal of Apicultural Research* 59: 1-8.

BRASIL. Ministério da Agricultura, Pecuária e do Abastecimento. Regulamento técnico geral para fixação dos padrões de identidade e qualidade para polpa de fruta. 2000. http://www.redejucara.org.br/legislacao/IN01_00MAPA_RegTecGeralPIQ_PolpaFruta.pdf<Acesso em 26 fev. 2021>

Carr, M.K.V. 2013. The water relations and irrigation requirements of passion fruit (*Passiflora edulis* Sims): A review. *Experimental Agriculture* 49: 585-596.

Cavalcante, A.G., Cavalcante, L.F., Souto, A.G.L., Cavalcante, A.C.P., Araújo, D.L., Nascimento, A.P.P., Zanuncio, J.C. 2020. Physiology and production of yellow passion fruit with hydroabsorbent polymer and different irrigation depths. *Revista Ceres* 67: 365-373.

Dias, D.G., Pegoraro, R.F., Maia, V.M., Medeiros, A.C. 2017. Production and postharvest quality of irrigated passion fruit after N-K fertilization. *Revista Brasileira de Fruticultura* 39: e-553.

Dutra, A.F., Melo, A.S. de; Brito, M.E.B., Suassuna, J.F., Dutra, W.F. 2018. Photochemical and productive performance of yellow passion fruit irrigated in the brazilian semiarid. *Engenharia Agrícola* 38: 901-909.

Figueiredo, F.R.A., Hafle, O.M., Rodrigues, M.H.B.S., Pereira Júnior, E.B., Delfino, F.I. 2015. Produtividade e qualidade dos frutos do maracujazeiro-amarelo sob diferentes formas de condução das plantas. *Agropecuária Científica no Semiárido* 11: 23-32.

Fischer, G., Melgarejo, L.M., Cutler, J. 2018. Pre-harvest factors that influence the quality of passion fruit: A review. *Agronomía Colombiana* 36: 217-226.

Francisco, W.M., Araújo Neto, S.E., Uchôa, T.L., Souza, L.G.S., Silva, N.M. 2020. Productivity and quality of irrigated organic yellow passion fruits in deep planting in Southeastern Amazon. *Revista Brasileira de Fruticultura* 42: e-584.

Galvão, R.O.; Araújo Neto, S.E., Silva, N.M., Souza, L.G.S.; Uchôa, T.L., Ferreira, R.L.F. 2020. Organic compost as a conditioner of soils cultivated with yellow passion fruit. *Comunicata Scientiae* 11: e3398.

IBGE. Instituto Brasileiro de Geografia e Estatística. Produção agrícola municipal – culturas temporárias e permanentes. 2020. http://www.sidra.ibge.gov.br/bda/tabela/ listabl.asp?c=1613&z=p&o=28<Acesso em 20 abr. 2021>

INMET. Instituto Nacional de Meteorologia. Banco de Dados Meteorológicos para Ensino e Pesquisa. 2020. http://www.inmet.gov.br/portal/index. php?r=bdmep/bdmep <Acesso em 18 abr. 2021>

Jesus, C.A.S., Carvalho, E.V., Girardi, E.A., Rosa, R.C.C., Jesus, O.N. 2018. Fruit quality and production of yellow and sweet passion fruit in Northern state of São Paulo. *Revista Brasileira de Fruticultura* 40: e-968.

Junqueira, C.N., Yamamoto, M., Oliveira, P.E., Hogendoorn, K., Augusto, S.C. 2013. Nest management increases pollinator density in passion fruit orchards. *Apidologie* 44: 729-737.

Koetz, M., Carvalho, J.A., Souza, A.M.G., Souza K.J. 2010. Qualidade de frutos do maracujazeiro-amarelo em ambiente protegido e natural produzidos sob diferentes regimes de irrigação. *Revista Brasileira de Agricultura Irrigada* 4: 115-127.

Krause, W., Neves, L.G., Viana, A.P., Araújo, C.A.T., Faleiro, F.G. 2012. Produtividade e qualidade de frutos de cultivares de maracujazeiro-amarelo com ou sem polinização artificial. *Pesquisa Agropecuária Brasileira* 47: 1737-1742.

Lage, L.A., Krause, W., Silva, C.A., Dias, D.C., Ambrósio, M., Cobra, S.S.O. 2018. Morphometry, floral resources and efficiency of natural and artificial pollination in fruit quality in cultivars of sour passion fruit. *Revista Brasileira de Fruticultura* 40: e-171.

Martarello, N.S., Gruchowski-Woitowicz, F.C., Agostin, K. 2021. Pollinator Efficacy in Yellow Passion Fruit (*Passiflora edulis* f. *flavicarpa* Deg., Passifloraceae). *Neotropical Entomology* 50: 349-357.

Mascarello, F.B., Araújo Neto, S.E., Silva, N.M., Machado, L., Rocha, C., Uchôa, T.L. 2019. Polinização artificial de diferentes números de estigmas na frutificação do maracujazeiro amarelo em cultivo orgânico. *Revista Brasileira de Ciências da Amazônia* 8: 1-14.

Meletti, L.M.M. 2011. Avanços na cultura do maracujá no Brasil. *Revista Brasileira de Fruticultura* 33: 83-91.

Nascimento, W.M.O. Tomé, A.T., Oliveira, M.S.P. Carvalho, J.E.U. 2003. Seleção de progênies de maracujazeiro-amarelo (*Passiflora edulis* f. *flavicarpa*) quanto à qualidade de frutos. *Revista Brasileira de Fruticultura* 25: 186-188.

Negreiros, J.R.S.; Araújo Neto, S.E., Álvares, V.S., Lima, V.A., Oliveira, T.K. 2008. Caracterização de frutos de progênies de meios-irmãos de maracujazeiro amarelo em Rio Branco – Acre. *Revista Brasileira de Fruticultura* 30: 431-437.

Rezende, M.I.F.L.; Araújo Neto, S.E., Lustosa, C., Hafle, O.M., Penha Pinto, G.P. 2017. Grafting for the recovery of yellow passion fruit stem in organic system. *Revista Brasileira de Fruticultura* 39: e-745.

Santos, H. G., Jacomine, P.K.T., Anjos, L.H.C., Oliveira, V.A., Coelho, M.R., Lumbreras, J. F., Almeida, J.A.; Cunha, T.J.F., Oliveira, J.B. 2013a. *Sistema Brasileiro de Classificação de Solos*. Embrapa, Brasília, Brasil. 354 p.

Santos, J.L.V., Resende, E.D., Martins, D.R., Gravina, G.A., Cenci, S.A., Maldonado, J.F.M. 2013b. Determinação do ponto de colheita de diferentes cultivares de maracujá.

Revista Brasileira de Engenharia Agrícola e Ambiental 17: 750-755.

Silva, N.M., Araújo Neto, S.E., Souza, L.G.S., Uchôa, T.L., Ferreira, R.L.F. 2019. Organic cultivation of yellow passion fruit using tall seedlings with long root systems. *Comunicata Scientiae* 10: 477-483.

Silva, N.M., Araújo Neto, S.E., Souza, L.G.S., Uchôa, T.L., Francisco, W.M., Pinto, G.P., Ferreira, R.L.F. 2021. Fenologia da floração e frutificação do maracujazeiro amarelo sob cultivo orgânico no sudoeste amazônico. *Brazilian Journal of Animal and Environmental Research* 4: 4861-4876.

Silva, N.M., Souza, L.G.S., Uchôa, T.L., Araújo Neto, S.E., Silva, S.O. 2020. Profitability of organic passion fruit production using tall seedlings and long root system. *Revista Caatinga* 33: 341-348.

Silveira, M.V., Abot, A.R., Nascimento, J.N., Rodrigues, E.T., Rodrigues, S.R., Puker, A. 2012. Is manual pollination of yellow passion fruit completely dispensable? *Scientia Horticulturae* 146: 99–103.

Uchôa, T.L.; Araújo Neto, S.E., Francisco, W.M., Silva, N.M. Souza, L.G.S., Pinto, G.P. 2021a. Economic profitability of yellow passion fruit in organic cultivation under different input levels and irrigation. *Comunicata Scientiae*, 12: e3409.

Uchôa, T.L.; Araújo Neto, S.E., Francisco, W.M., Souza, L.G.S., Silva, N.M. 2021b. Yield and quality of passion fruit under organic cultivation with input levels and irrigation in the state of acre. *Revista Caatinga* 34: 144-154.

Uchôa, T.L.; Araújo Neto, S.E., Selhorst, P.O., Rodrigues, M.J.S., Galvão, R.O. 2018. Yellow passion fruit performance in organic crop under mulch. *Revista Brasileira de Fruticultura* 40: e-212.

Vianna-Silva, H., Resende, E.D., Pereira, S.M.F., Viana, A.P., Rosa, R.C.C., Carlos, L.A., Vitorazi, L. 2008. Influência dos estádios de maturação sobre as características físicas dos frutos de maracujá-amarelo. *Bragantia* 67: 521-525.

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.