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QUALITY OF FRUITS PRODUCED BY IMPROVED VARIETIES OF SOUR *PASSIFLORAEDULIS* GRAFTED ON TO NATIVE *P. EDULIS* AND *P. SERRATODIGITATA* ROOT STOCKS

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ABSTRACT

This study aimed to evaluate the quality of fruits produced by improved varieties of sour *Passifloraedulis* Sims (FB 100, FB 200, UFAC 07, UFAC 38, UFAC 25, UFAC 64 and UFAC 70) grafted onto native. The field experiment followed a randomized block design with a 3 x 7 factorial scheme comprising 21 combinations of three rootstocks and seven scions with three repetitions of four plants per plot. Grafted plants were spaced at 3 m intervals in single trellis rows 5 m apart with supporting wires 2 m above ground. Fruits were harvested 380 days after planting and fruit length, fruit diameter, skin thickness, total soluble solids (TSS), total titratable acidity (TTA), TSS/TTA ratio, fruit mass and pulp yield were evaluated. In general, there were statistically significant differences between the fruits produced by the 21 combinations with respect to fruit length and diameter, but differences regarding the other parameters were either minor or inexistent. Based on fruit length and diameter, the varieties of *P. edulis* FB 200, UFAC 25 and UFAC 64 produced the best quality fruit regardless of the rootstock. In addition, *P. serratodigitata* rootstock tended to induce thicker skin in the fruits of FB 200 and UFAC 38.

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INTRODUCTION

Brazil is a major producer of passion fruit (*Passifloraedulis* Sims)with a planted area of 46,436 ha and a production of approximately 690,000tonof fruit according to data collected in 2020 (INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA, 2020).The largest producing areas are located in the states of Bahia, Ceará, Santa Catarina, Pernambuco, Minas Gerais, São Paulo and Alagoas. Taken together these states accounted for81% of the national production in 2022, although Bahia alone contributed29% of the total as represented by197, 160 ton of fruits harvested from17,412 ha. The average productivity of passion fruit in Brazil is around15 ton.ha^{-1}, a value that is well below the productive potential of the culture whilst, in the state of Acre, productivity is even lower at just 8 ton.ha^{-1}. Indeed, Acre contributed only 0.2% of the national production of passion fruit in 2022 and demand from within the state had to be supplied by importation from other regions. The low production and productivity, along with the poorer quality of the fruit, can be explained in part by the lack of technologies adapted to this northern region. For example, sexual propagation of inferior genetic material gave rise to underperforming orchards generating sourpassion fruit that were small, heterogeneous and susceptible to pests and diseases (AMBRÓSIO *et al*., 2018).

In order to exploit the full potential of passion fruit culture, it is important to develop applications and alternative production systems that are more suited to the climate and soil conditions of the region. In this context, effective grafting can confer productive plants with attributes of tolerance or resistance that enable them to grow under drought conditions or in soils infested with nematodes, pests and diseases, most especiallyfusarium wilt (*Fusariumoxysporum* f. sp. *passiflorae*). This widespread soil-borne phytopathogenicfungus penetrates the roots, extends to the tissues and colonizes xylem vessels, thereby interrupting the flow of sap and causing yellowing, wilting and premature death of plants. In the case of passion fruit, the presence of high fungal inocula in infected orchards precludes replacement of the perennial vines and such areas are typically abandoned. Healthy plants with appropriate characteristics can be formed by grafting scions bearing desirable traits originating from improved genotypes ontodisease-resistant/tolerant rootstocks (JUNQUEIRA *et al*., 2006). Moreover, the clonal propagation of selected plants for use as scions ensures the faithful transmission of the advantageous traits of the progenitors, unlike seed propagation in which the character alleles are segregated into different gametes and may not be maintained in the next generation. In this manner, homogeneous, productive and early-maturing orchards can be established using appropriately grafted plants (LIMA *et al*., 1999). There is evidence to suggest, however, that the use of native

Passifloras pecies as rootstocks can induce production of smaller passion fruits (CAVICHIOLI *et al*., 2008, 2009), while rootstocks comprising commercial species of sour *P. Edulis* and sweet *P. alata* tend to generatelarger fruits (CAVICHIOLI *et al*., 2011; NOGUEIRA FILHO *et al*., 2010, 2011). Thus, it might be expected that passion fruit with superior physicochemical properties would be obtained using *rootstocks of plants that produce fruits with* high total soluble solids (TSS) *and low* total *titratable acidity (TTA).However, although the fruits of native Passiflora species have* low TSS *and high TTA, the degree of influence of the rootstock on the quality of fruits produced by the scion variety remains controversial. Thus, according to Cavichioli et al. (2011),* the TSS, TTA and TSS/TTA values of fruits produced by sour *P. Edulis* when grafted onto the rootstocks *P. gibertii* N.E.Br or sweet *P. alata* were not affected, even though the fruits of the latter exhibited high TSS and low TTA. Considering that grafting techniques could boost the production of passion fruit in Acre, the aim of this study was to evaluate the quality of fruits produced by commercial and regional varieties of sour *P. edulis* grafted onto native *P. edulis* (sour and purple types) and *P. serratodigitata* L. that are more resistant to soil-borne diseases.

MATERIALS AND METHODS

The study was performed in the experimental nursery of Embrapa Acre (9º58'30"S, 67º48'36"W; altitude 160 m) located in the state capital Rio Branco. According to the Köppen classification, the climate of the region is AwI (tropical sub-humid) with maximum and minimum annual temperatures of 30.92 and 20.84°C, respectively, mean relative humidity of 83% and annual rainfall of 1,648.94 mm (AGRITEMPO, 2008). The field experiment followed a randomized block design with a simple 3 x 7 factorial scheme comprising 21 combinations of three rootstocks and seven scions with three repetitions of four plants per plot. The rootstocks employed in the experiment were native sour *P. edulis* (accession from Cuiabá, MT, Brazil), native purple *P. edulis* (*"roxinhomiúdo"*) and native *P. serratodigitata* (accessions from Instituto Agronômico de Campinas - IAC, Campinas, SP, Brazil). Native purple *P. edulis* produces small purple fruits with an elevated TSS value, while *P. serratodigitata* is resistant to fusarium wilt. Although native *P. alata* was included initially among the rootstocks, the species could not be employed in field experiments because it did not reach the grafting stage at the time of planting (RONCATTO *et al*., 2011).The scion varieties of sour *P. edulis* employed in the experiments were the commercial cultivars FB 100 and FB 200(Flora Brasil, Araguari, MG, Brazil; https://viveiroflorabrasil.com.br) that had been developedin the Araguari region from selected genotypes for both fresh consumption and industrial processing. These cultivars present fruits of around 240 g in weight with uniform size, shape and color, a thick skin that confers mechanical resistance during transport, a TSS of 14.0 ºBrix, a pulp yield of 36%and a potential productivity of 50 $t.ha^{-1}$. Regional cultivars of *P. edulis*, namely UFAC 07, UFAC 38, UFAC 25, UFAC 64 and UFAC 70 (Universidade Federal do Acre – UFAC, Rio Branco, AC, Brazil) were also used as scions in the experiments, although their fruit quality and productivity potential arestill under investigation. Seedlings of the scion varieties and native rootstock species were obtained by sowing 120 seeds of each in polyethylene tubes containing Plantmax® commercial vegetable substrate. Trays containing the tubes were placed inside a 50% screen-shaded greenhouse on masonry benches installed at 0.50 m above the ground. Watering was performed daily by means of a micro sprinkler system, and any roots that emerged from the limits of the container were pruned back. Full cleft grafting was carried out with hypocotyls, as described by Nogueira Filho *et al*. (2005), when scions and rootstocks were about 6 to 8 cm in height and with three definitive leaves, corresponding to around 30 days after sowing for the fast growing and more vigorous types and some 90 days for the slower growing types. Preparation of soil in the experimental area involved mechanical weeding followed by fertilization as described by Lima (2005). Liming was not required because the base saturation value was greater than 60% and magnesium concentration was more than 9 $mmol_c.dm^{-3}$.In each plot, rows were marked out to establish the location of line support posts and plants with 5 m spacing between lines and 3 m spacing between plants. Holes were opened up with the aid of a tractor-operated pit digger to depths of 1.2 m for posts and 0.5 m for plants. Support posts were installed and smooth training wires were fixed at a distance of 2 m from the ground, while the plant pits received localized fertilization with 40 g of FTE BR-12 and 1.18 kg of simple superphosphate to improve the nutrient foundation. Plants were transplanted to the prepared pits 30 days after grafting (22 December 2011) and the vines trained to grow as single stems towards the wires by means of small bamboo stakes and string lines linking the pit crowns and the support wires. Plants were watered twice a week until the start of the rainy season. During the vegetative stage, cover fertilization was provided individually to each plant by applying 22 g of urea at 30 days after planting (DAP), 33 g of urea at 60 DAP and 112 g of urea together with 83 g of potassium chloride at 90 DAP. During the fruit production stage, each plant received cover fertilization with 150 g simple superphosphate and 40 g FTE BR-12 at 270 DAP (September 2012) in addition to 0.7kgNPK (20:5:20) supplied in five equal parts from 270 to 360 DAP (September 2012 to January 2013). Plants were allowed to grow 10 cm above the support wires, following which the single stems were pruned to induce the emission of secondary branches. These branches were trimmed when they reached the neighboring plant in order to stimulate the formation of tertiary branches, and the tendrils were removed to allow the branches to develop in the form of a combed curtain. Plants were sprayed with a solution of copper oxychloride in water (3 $g.L^{-1}$) every 15 days commencing at 90 DAP to prevent/cure fungal and bacterial diseases, and with dimethoate (2 $mL.L^{-1}$) whenever necessary for the control of insect pests. Ten fruits from each plot were collected randomly at 380 DAP (February 2013) and analyzed in the Food Technology Laboratory at Embrapa Acre. In order to estimate the individual effects of each scion and rootstock, as well as possible interactions between the two factors, physical(fruit length, fruit diameter and skin thickness), chemical (TSS, TTA and TSS/TTA ratio) and agronomic (fruit mass and pulp yield) parameters were evaluated. Data from the 21 treatments were submitted to analysis of variance (ANOVA) and mean values of the variables were compared using the Scott-Knott test. The differences between mean values were considered statistically significant at the 5% probability level.

RESULTS AND DISCUSSION

There were significant differences regarding the length and diameter of the passion fruits produced by the 21 scion/rootstock combinations, but differences regarding skin thickness, TSS, TTA, TSS/TTA ratio, fruit mass and pulp yield were minor and not statistically significant. The grafted plants presenting the best performances in relation to the physical characteristics of the fruit were those involving scion varieties FB200, UFAC 25 and UFAC 64 and rootstocks sour/purple *P. edulis* and *P. serratodigitata* (Table 1). Of these combinations, FB 200/*P. serratodigitata* generated the largest fruits with mean length 75.35 mm and mean diameter 71.65 mm, while UFAC 70/purple *P. edulis* produced the smallest fruits with mean length 62.87 mm and mean diameter 62.06 mm. In general, the dimensionsof fruits obtained in the present study were slightly below the range of 70 to 90 mm reported previously for similar scion/rootstock combinations (NASCIMENTO *et al*. 1999; VIANNA-SILVA *et al*., 2008; CAVICHIOLI *et al*., 2008, 2009; NOGUEIRA FILHO *et al*., 2010). No statistically significant differences were detected between the 21 scion/rootstock combinations regarding mean skin thickness of the fruit (Table 1). The combination FB100/purple *P. edulis* generated fruit with the thinnest skin (3.91 mm), while the thickest (6.83 mm) was observed in fruit from FB200/*P. serratodigitata.* In its natural habitat, *P. serratodigitata* produces hard-shelled fruits that resemble gourds, and this characteristic may have been transferred from the rootstock to the scion. Although a thick skin is advantageous in terms of handling during storage and transport, it is also associated with lower pulp yield, which is another important characteristic not only for the fresh fruit market but also for industry. In practice, industrial processors prefer passion fruit with a thinner skin and with the internal cavity filled completely with pulp (BRUCKNER *et al*., 2002).

Table 1. Physical characteristics of passion fruit produced by 21 scion/rootstock combinations cultivated in Rio Branco, Acre, Brazil

Scion	Fruit length (mm)				Fruit diameter (mm)				Skin thickness (mm)			
	P. edulis[1]	*P. edulis*[2]	*P. serratodigitata*	Mean	*P. edulis*[1]	*P. edulis*[2]	*P. serratodigitata*	Mean	*P. edulis*[1]	*P. edulis*[2]	*P. serratodigitata*	Mean
FB 100	66.99	68.47	68.05	67.83[b]	64.68	66.11	66.87	65.89[b]	4.68	3.91	4.87	4.49
FB 200	72.45	69.46	75.35	72.42[a]	70.10	66.28	71.65	69.34[a]	5.47	5.39	6.83	5.89
UFAC 07	68.88	67.20	66.81	67.63[b]	70.66	69.87	68.09	69.54[a]	5.34	5.92	5.10	5.46
UFAC 38	62.55	69.56	65.73	65.95[b]	63.92	69.41	66.72	66.68[b]	4.94	5.10	6.28	5.44
UFAC 25	68.79	72.95	70.99	70.91[a]	68.13	72.05	68.69	69.62[a]	5.91	5.79	5.58	5.76
UFAC 64	70.43	71.95	69.49	70.62[a]	69.06	69.86	69.87	69.60[a]	5.71	5.51	5.30	5.50
UFAC 70	64.80	62.87	64.14	63.94[b]	65.59	62.06	62.64	63.43[b]	5.21	4.10	5.36	4.89
Overall mean	67.84	68.92	68.65		67.45	67.95	67.79		5.32	5.10	5.62	
CV[3] (%)	6.67				6.09				21.25			

[1]Mean values followed by dissimilar lowercase superscript letters are significantly different according to the Scott-Knott test at 5% probability
[2]Native sourtype; [3]Native purple type; [4]Coefficient of variation

Table 2. Chemical characteristics of passion fruit produced by 21 scion/rootstock combinations cultivated in Rio Branco, Acre, Brazil

Scions	Total soluble solids (TSS; ºBrix)				Total titratable acidity (TTA; mEq/100 mL pulp)			
	P. edulis[1]	*P. edulis*[2]	*P. serratodigitata*	Mean	*P. edulis*[1]	*P. edulis*[2]	*P. serratodigitata*	Mean
FB 100	13.90	14.13	13.63	13.89	4.25	4.36	4.70	4.44
FB 200	14.23	13.52	13.03	13.60	4.57	4.23	5.08	4.62
UFAC 07	14.36	12.21	13.67	13.41	4.56	4.56	5.39	4.84
UFAC 38	13.40	14.01	13.70	13.70	4.75	5.25	5.07	5.02
UFAC 25	13.45	13.97	13.34	13.59	4.50	5.07	4.63	4.73
UFAC 64	14.00	13.60	12.48	13.36	5.13	5.06	4.87	5.02
UFAC 70	14.35	14.57	13.37	14.09	4.60	4.32	3.78	4.24
Overall mean	13.96	13.71	13.32		4.62	4.69	4.79	
CV[3] (%)	9.32				19.51			

Mean values are not significantly different according to the Scott-Knott test at 5% probability
[1]Native sourtype; [2]Native purple type; [3] Coefficient of variation

Table 3. Agronomic characteristics of passion fruit produced by 21 scion/rootstock combinations cultivated in Rio Branco, Acre, Brazil

Scion	Fruit mass (g)				Pulp yield (%)			
	P. edulis[1]	*P. edulis*[2]	*P. serratodigitata*	Mean	*P. edulis*[1]	*P. edulis*[2]	*P. serratodigitata*	Mean
FB 100	85.22	83.98	95.27	88.16	44.30	36.33	35.47	38.70
FB 200	88.68	105.53	129.72	107.96	44.94	34.67	32.13	37.25
UFAC 07	107.56	96.32	88.76	97.55	31.76	26.96	40.58	33.10
UFAC 38	79.80	91.59	97.83	89.74	28.80	31.89	31.48	30.72
UFAC 25	107.16	91.85	108.20	102.40	30.50	32.61	37.89	33.67
UFAC 64	108.76	120.42	102.22	110.47	37.77	48.38	41.38	42.51
UFAC 70	84.72	75.8.3	81.03	80.53	31.65	34.38	40.36	35.46
Overall mean	94.56	95.07	100.43		35.67	47.89	37.04	
CV[3] (%)	29.59				84.34			

Mean values are not significantly different according to the Scott-Knott test at 5% probability
1Native sour type; 2Native purple type; 3 Coefficient of variation

As shown in Table 2, there were no statistically significant differences between the 21 scion/rootstock combinations regarding mean levels of TSS and TTA. Fruits presenting the lowest TSS (12.21 ºBrix) were generated by the combination UFAC 07/purple *P. edulis*, whilst the highest TSS (14.57 ºBrix) was observed with UFAC 70/sour *P. edulis*. The majority of the combinations tested produced fruits with TSS values slightly below the range 14.2 to 15 ºBrix reported by Junqueira *et al*. (2006). Mean TTA values varied from 3.78mEq/100 mL pulp (UFAC 70/*P. serratodigitata*) to 5.39mEq/100 mL pulp (UFAC 07/*P. serratodigitata*). Since TSS and TTA values are the main factors that determine the flavor of fruits, the ratio TSS/TTA represents one of the best benchmarks for evaluating fruit quality and consumer acceptance. In general, fruits witha high TSS/TTA ratio command greater consumer acceptance (JAYASENA & CAMERON, 2008).In the present study, the mean TSS/TTA ratios of passion fruit varied from2.66 when UFAC 64was employed as the scion to 3.32 when UFAC 70 was the canopy variety. Table 3 shows that there were no differences between the 21 scion/rootstock combinations regarding fruit mass and pulp yield. Mean fruit mass ranged from75.83 g for the combination UFAC 70/purple *P. edulis* to 129.72 g for FB 200/*P. serratodigitata*, while mean pulp yield varied from 26.96% (UFAC 07/purple *P. edulis*) to 48.38% (UFAC 64/purple *P. edulis*). The fruit mass values obtained in the present study were well below the range183.87 to209.32 greported by various authors, while mean pulp yields were within or somewhat above the documented range of 29.37 to 34.5% (NASCIMENTO *et al*. 1999; VIANNA-SILVA *et al*., 2008;CAVICHIOLI *et al*., 2008, 2009; NOGUEIRA FILHO *et al*., 2010). Conversely, Junqueira *et al*. (2006) reported fruit masses and pulp yields within the respective ranges102to136g and 42 to48%,values that are much closer to those reported herein. According to Cavichioli *et al*. (2011), the combination sour *P. edulis*/ *P. alata* produced fruits with masses up to 235 g implying that the rootstock, the native form of which produces large heavy fruits, had influenced the characteristics of the scion variety. In previous studies (NOGUEIRA FILHO, 2003; NOGUEIRA FILHO *et al*., 2005), observed that FB 200 grafted onto *P. edulis* or *P. alata* also gave rise to large fruits. Taken together, these results confirm that the rootstock exerts someimpact, even if very limited, on the characteristics of the fruits of the scion variety. Concerning the grafting process, successful combinations are generally associated with compatible diameters between scion and rootstock. In particular, when the graft components are attached at the early stages of plant development (at the seedling stage) the characteristics of non-uniformity in stem diameter and lignification of tissues are yet to be established, and this favors effective union and fusion of the vascular tissues in the grafting region (RONCATTO *et al*., 2011).

CONCLUSIONS

Discrimination between the quality of fruits produced by the various scion/rootstock combinations of improved varieties of sour *P. edulis* grafted onto native sour or purple *P. edulis* or *P. serratodigitata* was based exclusively on the size of the fruits (length and diameter), since the other variables (skin thickness, TSS, TTA, fruit mass and fruit yield) were not influence by grafting. Under the climate and soil fertilization conditions employed in our study, the best quality fruits were produced by sour *P. edulis* varieties FB 200, UFAC 25 and UFAC 64 grafted onto any of the three native rootstocks studied.

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