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Research Article

Compatibility and phenotypic variability of guava accessions grafted on BRS Guaraçá rootstock: vegetative and fruit production traits[1]

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ABSTRACT

One of the main problems faced by guava production is the decline caused by the root-knot nematode (*Meloidogyne enterolobii*), which has a wide distribution in Brazil. This study aimed to evaluate the productive and morphological compatibility and variability of guava accessions grafted on BRS Guaraçá, a rootstock with resistance to the root-knot nematode. The experiment was conducted with 83 accessions from the *Psidium* Germplasm Bank (Petrolina, Pernambuco State, Brazil). The evaluated traits were stem diameter, canopy diameter I and II, plant height, total number of fruits, total fruit weight, mean fruit weight, seed weight, pulp weight, fruit width and length. Except for the stem diameter ratio, all variables showed significant differences ($p < 0.05$), indicating phenotypic variability. The evaluated accessions showed no incompatibility symptoms, e.g., cracks, exudations and differences for stem diameter in the grafted area, indicating high compatibility. The accessions formed vigorous plants in the second harvest cycle, with mean canopy diameter of 2.3 m and mean plant height of 2.2 m, also indicating high compatibility. The accessions Gua64BA, Gua181ES, Gua06MA, Pedro Sato and Gua99AM showed the highest values for pulp and fruit weight (around 160 g), whereas Gua96AM, Gua70RO, Gua192ES, Gua01MA and Gua183ES showed the highest fruit production values (around 20 kg plant^{-1}), being recommended for grafting in BRS Guaraçá or as potential parents for population development.

KEYWORDS: *Psidium guajava*, *Meloidogyne enterolobii*, nematode infection.

RESUMO

Compatibilidade e variabilidade fenotípica de acessos de goiabeira enxertados em porta-enxerto BRS Guaraçá: características vegetativas e de produção de frutos

Um dos principais problemas enfrentados na produção de goiaba é o declínio causado pelo nematoide-das-galhas (*Meloidogyne enterolobii*), que possui ampla distribuição no Brasil. Objetivou-se avaliar a compatibilidade e variabilidade produtiva e morfológica de acessos de goiabeira enxertados em BRS Guaraçá, porta-enxerto com resistência ao nematoide-das-galhas. O experimento foi conduzido com 83 acessos do Banco de Germoplasma de *Psidium* (Petrolina, PE). As características avaliadas foram diâmetro do caule, diâmetro da copa I e II, altura da planta, número total de frutos, peso total do fruto, peso médio do fruto, peso da semente, peso da polpa, largura e comprimento do fruto. Com exceção da razão diâmetro do caule, todas as variáveis apresentaram diferenças significativas ($p < 0{,}05$), indicando variabilidade fenotípica. Os acessos avaliados não apresentaram sintomas de incompatibilidade, como rachaduras, exsudações e diferenças no diâmetro do caule na área enxertada, indicando alta compatibilidade. Os acessos formaram plantas vigorosas no segundo ciclo de colheita, com diâmetro médio de copa de 2,3 m e altura média de planta de 2,2 m, indicando, também, alta compatibilidade. Os acessos Gua64BA, Gua181ES, Gua06MA, Pedro Sato e Gua99AM apresentaram os maiores valores de polpa e peso de frutos (cerca de 160 g), enquanto Gua96AM, Gua70RO, Gua192ES, Gua01MA e Gua183ES apresentaram os maiores valores de produção de frutos (em torno de 20 kg planta^{-1}), sendo recomendados para enxertia em BRS Guaraçá ou como potenciais genitores para o desenvolvimento populacional.

PALAVRAS-CHAVE: *Psidium guajava*, *Meloidogyne enterolobii*, infecção nematoide.

INTRODUCTION

Guava (*Psidium guajava*) is an important tropical fruit species due to the nutritional quality, aroma and flavor of its fruits (Martins et al. 2020). This crop contributes significantly to the Brazilian fruit sector, with a total production of 584,223 tons in 2019 that achieved a revenue value close to US$ 200 million, with the Southeast and Northeast regions of Brazil accounting for 90 % of the national

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guava production (IBGE 2020). Guava fruits may be consumed fresh (*in natura*) or used to produce industrialized products, e.g., sweets, jams and preserves (Cañizares et al. 2003). Moreover, these fruits have significant contents of vitamin C, vitamin A and B-complex vitamins, lycopene and β-carotene (Manica et al. 2000).

The main problems faced by the Brazilian guava production is the disease known as guava decline, initially caused by the root-knot nematode (*Meloidogyne enterolobii*), with an economic impact estimated at US$ 66 million, in 2008 (Pereira et al. 2009). This complex disease increases the plant sensitivity to environmental stresses and causes the progressive rotting of affected roots, finally resulting in the plant death (Gomes et al. 2010). Early studies aimed at controlling this disease with nematicides, biological control, crop rotation and strawberry guava rootstocks did not show satisfactory results, either due to low control efficacy or incompatibility with grafted guava cultivars (Freitas 2012). Robaina et al. (2015) used *P. cattleyanum* as a rootstock for the guava cultivar Paluma and observed low seedling vigor and incompatibility symptoms, highlighting the limitations of this strategy.

Other research results indicate the BRS Guaraçá hybrid from *P. guajava* × *P. guineense* as a nematode-resistant rootstock compatible with the guava cultivars Paluma and Pedro Sato, producing 40 t ha^{-1} $year^{-1}$ (Souza et al. 2018). However, broader studies evaluating the BRS Guaraçá rootstock with a larger number of guava accessions, as well as other *Psidium* species, have not yet been conducted. Misra (2017) reported an F1 population of *P. molle* × *P. guajava* with resistance to wilt (*Fusarium oxysporum* and *F. solani*) and serving as a compatible rootstock for any guava variety. Some studies conducted with different species also reported compatibility between rootstock and scions. According to Bowmana & Joubert (2020), most citrus rootstocks are graft-compatible with most citrus scions, with few exceptions. In another study, Gonçalves et al. (2019) evaluated the compatibility of the peach cultivar BRS Libra with 23 clonal rootstocks and identified compatible and incompatible rootstocks. Furthermore, Vršič et al. (2015) evaluated the compatibility of different rootstocks with grapevine varieties, with one of them showing high compatibility with 12 rootstocks.

For Hartmann et al. (1997), graft compatibility is related to the satisfactory union between rootstock and scion and good plant development after grafting. According to Melnyk (2016), a successful grafting begins with the effective adhesion between rootstock and scion, followed by the formation of callus tissue at the graft interface, and ends with the establishment of vascular connections followed by the distribution of nutrients and water throughout the plant body. Conversely, incompatibility may result in increased diameter of the rootstock-scion union area, graft breakage or rupture, premature plant death, leaf yellowing or premature leaf fall (Fachinello et al. 1995). According to He et al. (2018), information on graft incompatibility mechanisms is still limited, and several studies have found that hormones, especially auxin, play significant roles in regulating the development and metabolic traits of higher plants. According to these authors, the content of indole-3-acetic acid (IAA) also increases with compatible graft combination, suggesting that IAA might promote graft compatibility.

In this scenario, the present study evaluated the productive and morphological compatibility and variability of 83 *P. guajava* accessions grafted on BRS Guaraçá, a root-knot nematode-resistant rootstock, aiming to identify limitations and accessions with greater agronomic potential.

MATERIAL AND METHODS

The experiment was conducted with 83 accessions from the *Psidium* Active Germplasm Bank (BAG *Psidium*), located at the Embrapa Semiárido, in Petrolina, Pernambuco State, Brazil (09º08'12.3"S, 40º18'31.6"W and 363 m above the sea level). The guava accessions were collected from different regions of the Brazilian States of Amazonas, Bahia, Espírito Santo, Goiás, Maranhão, Minas Gerais, Pernambuco, Piauí, Roraima, Rio Grande do Sul, Sergipe and Rondônia. The two final letters in the name of the accession identify the State where the material was collected. The soil of the experimental area is an Argissolo Vermelho-Amarelo Distrófico plíntico (Santos et al. 2018) or Ultisol (USDA 2014). The mean temperature is 26 ºC, with a hot and dry climate classified as BSh, according to Köppen, and the mean rainfall is 496 mm (Alvares et al. 2013). The transplanting of all plants occurred from April to May of 2018.

The experimental design was randomized blocks, with two replications and two plants per plot, spaced at 4 x 4 m. The root-knot nematode-resistant guava cultivar BRS Guaraçá was used as a rootstock. The rootstock cuttings were propagated in a nursery with suitable conditions for rooting. Seedlings of the BAG *Psidium* accessions, used as scions, were also propagated by seeds in a plant nursery, transplanted to plastic bags and kept under controlled irrigation conditions. The guava accessions were then wedge-grafted in the field at four months after transplanting, and irrigation was performed with a micro-sprinkler system. The area was sprayed to control pests and diseases, and weed control was performed by manual and mechanical hoeing. Finally, the plants were subjected to formative pruning, and the first fruit production pruning was performed in August 2019, with a new production pruning occurring in November 2019.

The evaluation cycle of the 83 guava accessions began in November 2020, by considering the following vegetative traits: plant height (m); stem diameter ratio at 15 cm below and 15 cm above the grafting point; canopy diameter I and II (m). The evaluated production traits were: total number of fruits; mean fruit weight (g); total fruit weight (kg); seed weight (g); pulp weight (g); fruit width and length (mm). Additionally, the accessions were visually evaluated for the presence of cracks and resins in the grafted area of the rootstock.

The data of all variables were subjected to analysis of variance, and the means were compared using the Student-Newman-Keuls test. These analyses were performed using the GLM procedure of the SAS software. The pulp weight and total fruit weight variables were transformed to square root, in order to meet the assumptions of normality. Finally, histograms were constructed using a Microsoft Excel spreadsheet to evaluate the dispersion of the measured traits.

The adopted statistical model used within-plot data, as described by Santos et al. (1995): $Y_{ijk} = \mu + a_i + b_j + e_{ij} + \pi_{ijk}$, where: Y_{ijk} is the value observed in the k-th plant, in the j-th replicate of the i-th accession; μ the overall mean; a_i the effect of the i-th accession, associated with the expected mean square [E(QM)] σ^2_A, genetic and environmental variance; b_j the effect of block j; e_{ij} the effect of the j-th replicate of the i-th accession, associated with E(QM) σ^2_E, environmental variance; π_{ijk} the effect of the k-th plant, in the j-th replicate of the i-th accession, associated with E(QM) σ^2_A, genetic and environmental variance.

RESULTS AND DISCUSSION

The analyzed variables showed significant statistical differences among the 83 accessions, indicating phenotypic variability, except for the stem diameter ratio at 15 cm below and 15 cm above the grafting point. The statistical significance was $p < 0.01$ for the analyzed variables, except for canopy diameter II ($p < 0.05$). The coefficients of variation ranged from 8.0 to 46.6 % for the analyzed traits, indicating good to limited experimental accuracy in the data measurement (Table 1).

For the studied variables, the variance between plants showed no significant differences by the F-test, indicating no phenotypic variability between plants of a given accession (Table 1). For Pommer & Murakami (2009), guava has a cross-pollination rate of up to 41.3 %, resulting in high phenotypic variability when propagated by seeds. This variability was not observed in the present study, probably due to the low number of plants (four) evaluated per accession.

The grafting success rate was approximately 100 %, although some accessions required re-grafting. This high grafting success rate may be attributed to the fact that the BRS Guaraçá has 50 % of the genome from a guava mother plant, the GUA161PE.

The stem diameter ratio at 15 cm below and 15 cm above the grafting point ranged from 0.73 to 1.14 (Table 1), with most accessions showing values from 0.8 to 1.1, two accessions showing values < 0.8, and other five accessions with values > 1.1 (Figure 1A), indicating good compatibility in the grafted area for 95 % of the accessions grafted on the BRS Guaraçá rootstock. There were no visual signs of cracks or resins in the grafted area, especially in the accessions with the lowest and highest stem diameter ratio at 15 cm below and 15 cm above the grafting point values (Figure 2). Moreover, the stem in the grafted area had an almost continuous color and brownish spots typical of the *Psidium* genus, indicating compatibility between scion and rootstock.

For Pereira et al. (2014), the presence of necrosis and excessive stem diameter below, above or at the grafted area are associated with graft incompatibility. Grigolo et al. (1997) also reported

Table 1. Mean squares and mean and coefficient of variation (CV) for the traits mean fruit weight (Mfw; g), pulp weight (Pul; g), total number of fruits per plant (Nfp), total fruit weight per plant (Tfw; kg), seed weight per fruit (Swf; g), fruit width (Frw; mm), fruit length (Frl; mm), stem diameter ratio at 15 cm below and 15 cm above the grafting point (Sdr), canopy diameter I (Cd1; m), plant height (Plh; m) and canopy dimeter II (Cd2; m) measured in 83 guava accessions grafted on BRS Guaraçá rootstock.

Source of variation	Mean squares										
	Mfw$^{1/}$	Pul	Nfp$^{1/}$	Tfw$^{1/}$	Swf	Frw	Frl	Sdr	Cd1	Plh	Cd2
Block	0.024^{ns}	824.14^{ns}	1,826.86**	115.70**	1,018.61**	11.92^{ns}	32.25^{ns}	0.0113^{ns}	0.38*	0.032^{ns}	0.8789**
Accessions	4.39**	1,162.50**	35.23**	1.76**	94.51**	70.57**	105.42**	0.0116^{ns}	0.15**	0.075**	0.1269*
Variation between	2.48^{ns}	859.41^{ns}	25.30^{ns}	2.55^{ns}	48.54^{ns}	7.54^{ns}	15.68^{ns}	0.023^{ns}	0.04^{ns}	0.067^{ns}	0.0407^{ns}
Variation within	1.27	358.67	14.67	0.85	51.12	17.18	33.11	0.0117	0.083	0.037	0.0893
Range	23.0-179.2	19.9-160.0	5-358	0.3-19.3	0.4-45.3	31.8-68.2	31.6-75.4	0.73-1.14	1.6-3.0	1.6-2.9	1.7-2.9
Mean	76.2	61.00	111.58	7.13	15.33	49.72	52.27	0.98	2.33	2.15	2.43
CV(%)	13.1	31.1	43.5	40.2	46.6	8.3	11.0	11.0	12.4	9.0	12.3
	Mfw	Pul	Nfp	Tfw	Swf	Frw	Frl	Rsd	Cd1	Plh	Cd2
Accessions with the five lowest values											
	Gua73RO	Gua73RO	Gua89AM	Gua89AM	Gua147BA	Gua17MA	Gua17MA	Gua82RO	Gua33PE	Gua33PE	Gua22MA
	Gua59SE	Gua17MA	Gua64BA	Gua64BA	PedroSato	Gua73RO	Gua95AM	Gua67RO	Gua22MA	Gua89AM	Gua23MA
	Gua02MA	Gua59SE	Gua181ES	Gua145BA	Gua23MA	Gua02MA	Gua01MA	Gua70RO	Gua23MA	Gua145BA	Gua89AM
	Gua83AM	Gua35PE	Gua47PE	Gua181ES	Gua15MA	Gua01MA	Gua84AM	Gua86AM	Gua15MA	Gua146BA	Gua33PE
	Gua145BA	Gua66RO	Gua21MA	Gua47PE	Gua31PI	Gua83AM	Gua73RO	Gua26MA	Gua35PE	Gua135RR	Gua105RS
Accessions with the five highest values											
	Gua53SE	Gua64BA	Gua67RO	Gua96AM	Gua35PE	Gua50SE	PedroSato	Gua99AM	Gua83AM	Gua132RR	PedroSato
	Gua51SE	Gua181ES	Gua35PE	Gua70RO	Gua150BA	Gua53SE	Gua06MA	Gua145BA	Gua88AM	Gua192ES	Gua82RO
	PedroSato	Gua06MA	Gua83AM	Gua192ES	Gua51SE	PedroSato	Gua35PE	Gua32PE	Gua26MA	Gua142RR	Gua73RO
	Gua06MA	PedroSato	Gua01MA	Gua01MA	Gua50SE	Gua06MA	Gua25MA	Gua75RO	Gua111GO	Gua84AM	Gua88AM
	Gua99AM	Gua99AM	Gua183ES	Gua183ES	Gua03MA	Gua99AM	Gua99AM	Gua65RO	Gua95AM	Gua22MA	Gua84AM

^{ns}, ** and *: non-significant and significant at 1 and 5 %, respectively, by the F-test. $^{1/}$ Data transformed to root square.

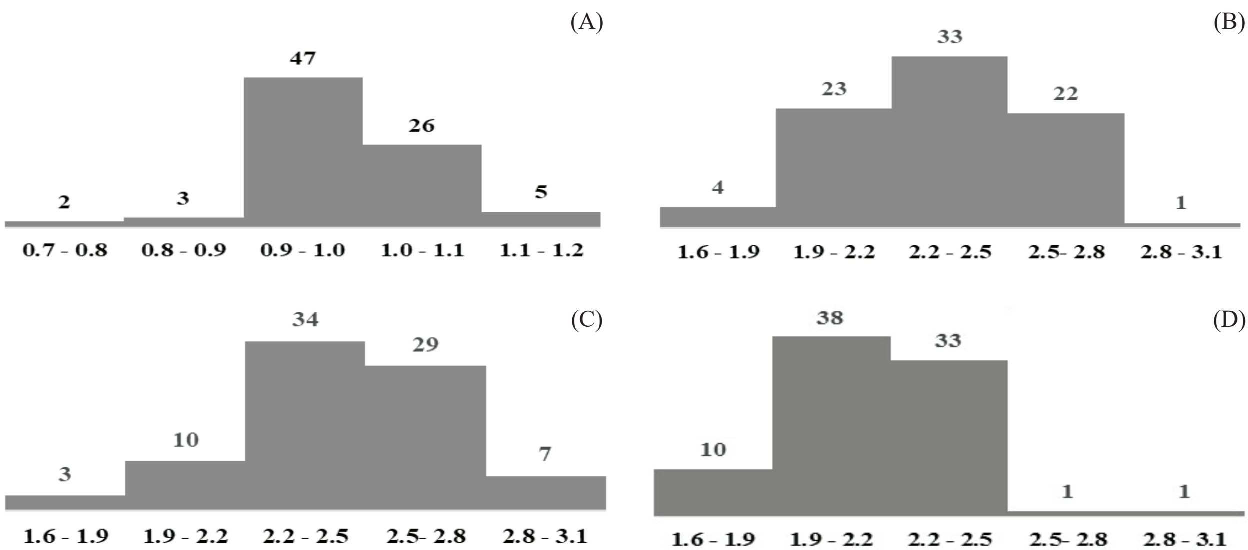

Figure 1. Frequency of vegetative traits of guava accessions evaluated for compatibility with the BRS Guaraçá rootstock. A) Stem diameter ratio at 15 cm below and 15 cm above the grafting point; B) canopy diameter I (m); C) canopy diameter II (m); D) plant height (m).

Photos: Carlos Antonio da Silva

Figure 2. Plants without incompatibility symptoms in the field. A and B: plants with lower stem diameter ratio at 15 cm below and 15 cm above the grafting point values; C and D: plants with higher stem diameter ratio at 15 cm below and 15 cm above the grafting point values. The arrows indicate the grafted area.

the absence of incompatibility in grapevine grafted on different rootstocks and highlighted the greater suitability of more vigorous rootstocks, as reported for the BRS Guaraçá (Souza et al. 2018).

Oliveira et al. (2014) studied the affinity between *P. guajava* × *P. guineense* and reported a high genetic proximity between these species when assessing the genetic divergence of *Psidium* accessions using molecular markers. Campos et al. (2017) emphasized that the affinity between scion and rootstock is essential for the grafting success, and, consequently, for the production of grafted seedlings.

Robaina et al. (2015) evaluated the Paluma guava cultivar grafted on strawberry guava (*P. cattleyanum*) aiming at nematode resistance and observed incompatibility and low vigor, highlighting the unsuitability of strawberry guava as a rootstock for Paluma.

The present study corroborates the results obtained by Souza et al. (2018), when evaluating the compatibility of guava cultivars grafted on the *P. guajava* × *P. guineense* hybrid, resulting in a high compatibility between rootstock and scion diameter and no exudations or cracks in the stem of grafted plants.

The canopy diameter I ranged from 1.6 to 3.0 m, whereas the canopy dimeter II ranged from 1.7 to 2.9 m, with the accessions Gua22MA, Gua23MA and Gua33PE showing the lowest values for canopy diameter I and II (Table 1). The plant height ranged from 1.6 to 2.9 m, with Gua33PE showing the lowest values for canopy diameter I and II and plant height (Table 1).

For canopy diameter, 94 % of the accessions showed values ranging from 1.9 to 2.8 m (Figure 1B). In contrast, for canopy diameter II, 88 % of the accessions showed values ranging from 1.9 to 2.8 m (Figure 1C). For plant height, 87 % showed values from 1.9 to 2.6 m (Figure 1D). Overall, these data also indicate the absence of incompatibility among the accessions grafted on the BRS Guaraçá rootstock and the existence of variability for canopy diameter I/II and plant height among the evaluated accessions. This variability may be exploited to develop new, small-sized cultivars, thus facilitating fruit harvest.

The fruit weight ranged from 31.8 to 179.2 g, with a mean value of 76.2 g (Table 1). For this variable, 64 % of the accessions showed values ranging from 60 to 120 g (Figure 3A). On the other hand, the pulp weight showed a mean value of 61.0 g and ranged from 19.9 g in the accession Gua59SE to 160 g in Gua73RO (Table 1). For this variable, 78 % of the accessions showed values ranging from 30 to 90 g (Figure 3B). Hussain et al. (2013) emphasized that fruit weight is an essential characteristic for producers and consumers, with medium to large fruits contributing to a greater market acceptance.

The total number of fruits ranged from 5 to 358, whereas the total fruit weight in the plant ranged from 0.3 to 19.7 kg, with the accessions Gua89AM and Gua183ES showing the minimum and maximum values for these variables, respectively (Table 1). Approximately 50 % of the accessions produced less than 60 fruits $plant^{-1}$, whereas 12 % of the studied accessions produced more than 240 fruits $plant^{-1}$ (Figure 3C). For total fruit weight, 14 accessions had more than 12 kg of fruits $plant^{-1}$ (Figure 3D).

Gonçalves et al. (2019) studied the vegetative and productive performance and fruit quality of peach grafted on 23 rootstocks and observed differences in the productive performance. However, the authors emphasized that the production values obtained should not be considered the maximum potential of the rootstocks, since only the first production cycle was evaluated. Likewise, the fruit production values reported in the present study also should not be considered the maximum production potential of the evaluated accessions.

In a study conducted by Souza et al. (2018), the mean values for total number of fruits, mean fruit weight and total fruit weight differed significantly between harvests. The fruit yield of the guava cultivars Paluma and Pedro Sato grafted on the hybrid rootstock was approximately 40 t ha^{-1}, ten times higher than in ungrafted Paluma.

The mean seed weight was 15.3 g, ranging from 0.4 g in Gua147BA to 48.4 g in Gua03MA. Pedro Sato appears among the five accessions with the lowest seed weight values, thus reaffirming one of the traits for this cultivar, which is its small number of seeds (Table 1). For seed weight, 78 % of the accessions showed values ranging from 8 to 24 g, indicating fruits with fewer seeds (Figure 3E).

The fruit width ranged from 9.9 to 69.3 mm, whereas the fruit length ranged from 7.7 to 77.0 mm, with the accessions Gua01MA, Gua17MA and Gua73RO showing the lowest values for both variables. Most accessions showed values ranging from 38 to 62 mm for fruit width (88 %) and fruit

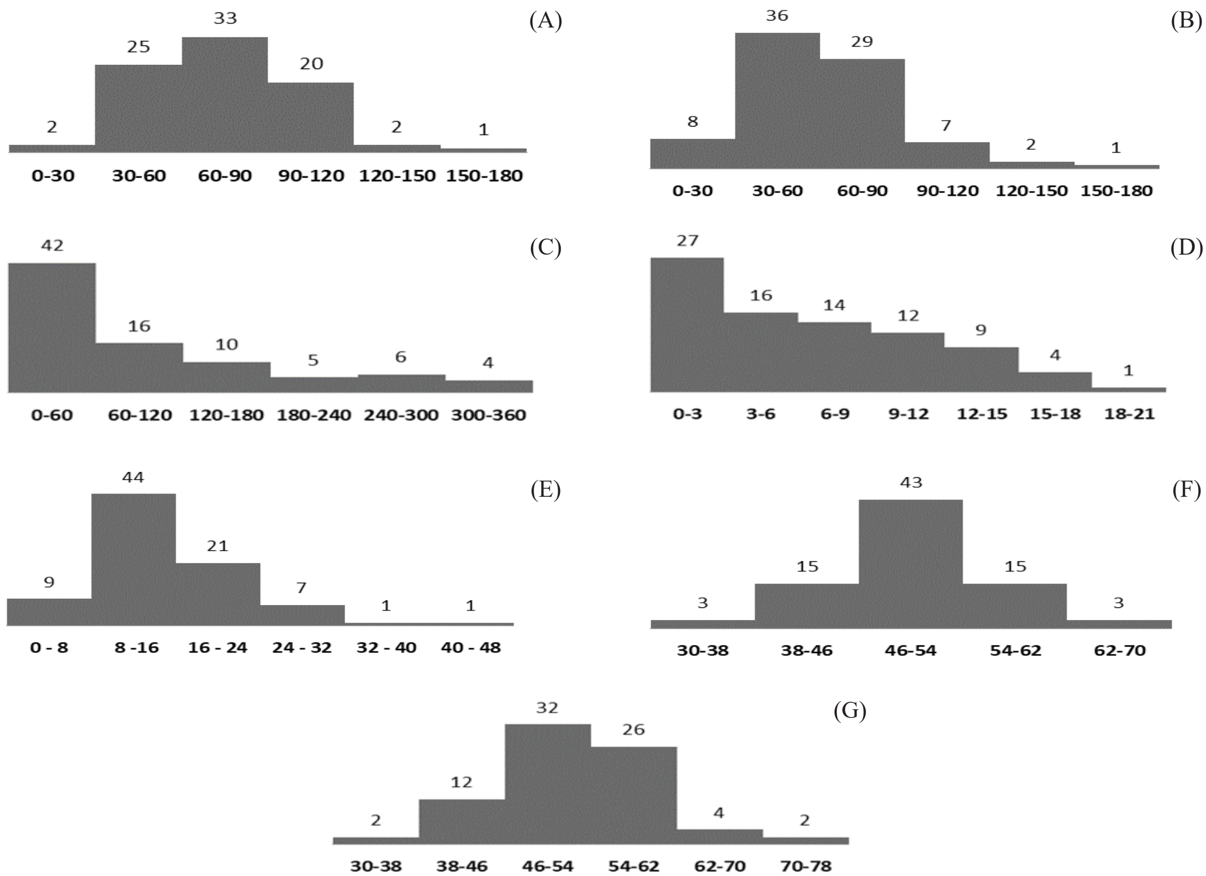

Figure 3. Frequency of fruit production traits of *Psidium guajava* accessions evaluated for compatibility. A) Mean fruit weight (g); B) pulp weight (g); C) total number of fruits; D) total fruit weight (kg); E) seed weight (g); F) fruit width (mm); G) fruit length (mm).

length (84 %) (Figures 3F and 3G). Pedro Sato stood out among the five highest values for mean fruit weight, pulp weight, fruit width, fruit length and canopy length. Among the evaluated accessions, Gua06MA and Gua99AM stood out with the highest values for mean fruit weight, pulp weight, fruit width and fruit length (Table 1).

Vigorous rootstocks translocate water and nutrients more efficiently and show a greater production of growth-promoting substances, thus favoring the canopy development (Pauletto et al. 2001). The present study highlighted the absence of incompatibility symptoms among *P. guajava* accessions grafted on a nematode-resistant rootstock, with plants showing a mean canopy diameter of 2.3 m and a mean plant height of 2.2 m. Gua64BA, Gua181ES, Gua06MA, Pedro Sato and Gua99AM showed the highest values for pulp and fruit weight, whereas Gua96AM, Gua70RO, Gua192ES, Gua01MA and Gua183ES resulted in plants with greater fruit production, demonstrating their commercial potential for grafting on the BRS Guaraçá rootstock.

CONCLUSIONS

1. There were no incompatibility symptoms, e.g., cracks, exudations and differences in stem diameter in the grafted area, among the 83 guava accessions grafted on the BRS Guaraçá rootstock, indicating a high compatibility after the second harvest cycle;
2. The accessions Gua64BA, Gua181ES, Gua06MA, Pedro Sato and Gua99AM showed the highest values for pulp and fruit weight (around 160 g), whereas Gua96AM, Gua70RO, Gua192ES, Gua01MA and Gua183ES showed a greater fruit production (around 20 kg plant^{-1}), demonstrating their suitability for grafting on the BRS Guaraçá rootstock.

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