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Original article

# Field resistance to *Meloidogyne enterolobii* in a *Psidium guajava* × *P. guineense* hybrid and its compatibility as guava rootstock

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## Summary

*Introduction* – **The objectives of this study were to evaluate resistance to *Meloidogyne enterolobii* in a *Psidium* hybrid and its compatibility as rootstock for two guava cultivars in order to be commercially released.** *Materials and methods* – **The treatments consisted of guava cv. Paluma scions without grafting, hybrid scions without grafting, and hybrid scions as rootstock for 'Paluma' and 'Pedro-Sato' guava cultivars. The number of eggs and juveniles of *M. enterolobii* in the soil and roots, guava decline symptoms, plant architecture, and fruit production were evaluated up to 24 months after transplanting (MAT).** *Results and discussion* – **The infestation by eggs and juveniles in the roots of 'Paluma' differed from infestation in the roots of the hybrid in five evaluation times, except at 6 MAT. The highest infestation by juveniles in the roots for all treatments occurred at 24 MAT, when the magnitude of the infestation in 'Paluma' was almost 540 times higher than the average infestation of the hybrid. The guava cultivars grafted onto the hybrid had fruit yield of approximately 40 t ha$^{-1}$ at 30 MAT, which was 10 times higher than that of the cv. Paluma without grafting. Stem diameter and canopy width were higher ($P$<0.01) for the cultivars grafted onto the hybrid compared to the 'Paluma' scion.** *Conclusion* – **Guava decline symptoms in 'Paluma' without grafting ranged from severe to plant death, whereas only one plant of the hybrid had moderate guava decline. The hybrid has proved to be resistant to the pathogen and showed excellent compatibility as rootstock for guava cultivars; it should be used as an alternative management practice for preventing damage from this nematode.**

**Keywords**
guava, *Psidium* spp., root-knot nematode, pest resistance, fruit yield, grafting

## Résumé

Résistance au champ de l'hybride *Psidium guajava* × *P. guineense* à *Meloidogyne enterolobii* et compatibilité comme porte-greffe de goyavier.

*Introduction* – **Cette étude avait pour but d'évaluer la résistance au nématode *Meloidogyne enterolobii* chez un hybride de *Psidium* et sa compatibilité en tant que porte-greffe pour deux cultivars de goyave afin d'être commercialisés.** *Matériel et méthodes* – **Les traitements consistaient à comparer le goyavier cv. Paluma non greffé, les scions d'hybrides greffés ou non greffés sur les porte-greffe de goyavier 'Paluma' et 'Pedro-Sato'. Le nombre d'œufs et de juvéniles de *M. enterolobii* dans le sol et les racines, les symptômes de dépérissement du goyavier, l'architecture des plantes et la production de fruits ont été évalués jusqu'à 6 mois après transplantation (MAT).** *Résultats et discussion* – **L'infestation des racines de 'Paluma' par les œufs et les juvéniles différait de l'infestation des racines de l'hybride tout au long de d'évaluation, sauf à 6 MAT. La plus forte infestation par les juvéniles dans les racines pour tous les traitements s'est produite à 24 MAT: l'ampleur de l'infestation était presque 540 fois plus élevée sur 'Paluma' que sur l'hybride. Les cultivars de goyavier greffés sur l'hybride ont eu des rendements fruitiers d'environ 40 t ha$^{-1}$ à 30 MAT, soit 10 fois plus élevés que ceux du cv. Paluma non greffé. Le diamètre de la tige et la largeur de la canopée étaient plus élevés ($P$<0,01) pour les cultivars greffés sur l'hybride comparativement au scion de 'Paluma'.** *Conclusion* – **Les symptômes de dépérissement du goyavier chez 'Paluma' non greffé allaient du stade sévère à la mort de la plante, tandis qu'une seule plante de l'hybride présentait un déclin modéré. L'hybride est bien résistant à l'agent pathogène et**

## Significance of this study

*What is already known on this subject?*
- *Meloidogyne enterolobii* is a guava pest of worldwide importance with a huge devastating impact in production areas in Brazil.

*What are the new findings?*
- Evaluation of a *Psidium guajava* × *P. guineense* rootstock resistant to *M. enterolobii* and highly compatible with guava cultivars.

*What is the expected impact on horticulture?*
- Effective control of *M. enterolobii* for preventing damage in guava orchards, with no additional costs or harm to the environment.

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**présente une excellente compatibilité en tant que porte-greffe avec les cultivars de goyaviers. L'utilisation de cet hybride doit devenir une pratique de gestion alternative pour prévenir les dommages causés par ce nématode.**

**Mots-clés**
goyave, *Psidium* spp., nématode à galles, résistance, production de fruits, greffage

## Introduction

Guava (*Psidium guajava* L.) is indigenous to Central and South America. This plant species belongs to the Myrtaceae family, which has about 130 genera with 3,000 shrub and tree species (Al-edany and Al-saadi, 2012). Guava is predominantly found in tropical and subtropical climates; however, it can be found almost everywhere in the world due to its ease in adaptation to various climates and in propagation through seeds (Gonzaga Neto, 2007). This species is cultivated in almost all Brazilian states, with a total area of 14,982 hectares and production of 349,615 t in 2013 (Agrianual, 2016). Guava is socioeconomically important mainly because it has a high level of vitamin C and can be consumed fresh or processed as preserves, jellies, or juices.

However, guava producers have been challenged by guava decline, a complex disease involving the nematode *Meloidogyne enterolobii* and the fungus *Fusarium solani*. The parasitism caused by the *M. enterolobii* facilitates the entrance of the fungus *F. solani* into the plant root system, causing this disease (Gomes *et al.*, 2013). *M. enterolobii* in guava plantations was reported for the first time in Brazil in Petrolina, state of Pernambuco, and Curaçá and Maniçoba, state of Bahia (Carneiro *et al.*, 2001). The severity of the damages and losses caused by *M. enterolobii* in guava trees decreased the planted area from 6,000 to 2,500 ha in the Petrolina region (Carneiro *et al.*, 2006).

Nematode control practices, such as the application of systemic soil nematicides that are not registered for guava trees, management practices with natural pesticides, and grafting onto resistant species of *Psidium* spp. have not yet achieved effective control of the pathogen (Carneiro *et al.*, 2007; Almeida *et al.*, 2011). According to Freitas (2012), among three species of *Psidium* resistant to the nematode, only *P. friedrichsthalianum* survived in the field as rootstock for the cultivar Paluma, with limited compatibility.

Castro *et al.* (2012) conducted an extensive evaluation of guava germplasm and *Psidium* spp. in different Brazilian states and reported the absence of sources of resistance to this nematode between or within guava accessions, and variable resistance between and within wild *Psidium* spp. accessions. Costa *et al.* (2012) developed a hybrid (*P. guajava* × *P. guineense*) resistant to this nematode. In experimental fields, plants of this hybrid showed growth similar to guava and high compatibility as rootstock for the cv. Paluma. However, this hybrid must be evaluated in production areas to be released as commercial rootstock for guava cultivars.

Nyczepir *et al.* (2008) and Rubio-Cabetas *et al.* (2009) reported the use of rootstock of *Prunus* spp. for control of *M. enterolobii* (= *M. mayaguensis*) in peach cultivars. However, there are no reports in the literature on the use of rootstock for root-knot nematode control in guava.

The objectives of this study were to evaluate the resistance to *M. enterolobii* in a guava hybrid (*P. guajava* × *P. guineense*) and its compatibility as rootstock for the guava cultivars Paluma and Pedro-Sato, the most important Brazilian cultivars, in commercial guava orchards in Petrolina, Pernambuco, Brazil.

## Materials and methods

### Plant material

Thirty hybrids were established by seeds at the Embrapa Experimental Field Station, Petrolina, Pernambuco, Brazil. This set, aged five years, originated from seedlings of a single cross, as described by Costa *et al.* (2012).

Scions of the 30 hybrid plants were obtained by grafting, according to procedures described by Zietemann and Roberto (2007). Cuttings with 2 or 3 buds were taken from young non-lignified branches, leaving a pair of upper leaves cut in half. The basal part of the cuttings was immersed in an indolebutyric acid solution (1,500 mg $L^{-1}$). The cuttings were immediately placed for rooting in 290-$cm^3$ tubes containing a commercial substrate, in which they were maintained for 120 days under intermittent water nebulization in a greenhouse.

Scions in good vegetative condition were selected for first transplanting in perforated plastic bags containing a mixture of soil, cattle manure, fine sand, and commercial substrate (2:1:1:1). The hybrid scions were maintained in a greenhouse with intermittent irrigation for 150 days. The scions were then definitively transplanted to soils infested with *M. enterolobii* in four guava commercial areas (Petrolina, PE) for evaluation under farmer's field conditions.

### Evaluation of resistance to *Meloidogyne enterolobii* in the *Psidium* hybrid and its compatibility as guava rootstock

Evaluation of the infestation of eggs and juveniles of *Meloidogyne enterolobii* were performed according to procedures described by Costa *et al.* (2012). The 30 five-year-old *Psidium* hybrid plants were evaluated for *M. enterolobii* eggs and juveniles, without any field experimental design.

Four sites were used for the assessment, with four treatments each and 10 plants per treatment, considering a randomized block design. The treatments in each site consisted of 10 scions of the guava 'Paluma' without grafting, 10 scions of the hybrid without grafting and 20 scions of the hybrid as rootstock for the guava cvs. Paluma (10 scions) and Pedro-Sato (10 scions). The tree spacing used in the areas was 6 × 4 m. The cultural practices were defined by each grower, including pruning, according to guava crop management adopted in the region. The grafting (cleft grafting method) was performed directly in the field, at four months after transplanting (MAT) the scions. Two months after the grafting, the success of the grafting was assessed.

Soil and root samples of five plants per treatment were sampled at 6, 12, 18, 24 and 30 MAT to evaluate the hybrid resistance to *M. enterolobii*. Ten g of roots and 100 g of soil were collected in each plant and individually processed 24 h after. The roots were ground in a blender using sodium hypochlorite solution (0.5%), for 20 to 30 s, in low speed, to release the eggs, as described by Hussey and Barker (1973). The extraction from the soil was performed using the technique described by Jenkins (1964). The analyses were carried out in the Embrapa Semiarid Nematology Laboratory.

The plants were visually assessed for symptoms of guava decline, such as burning of leaf edges, yellowing, and leaf drop using the following grading scale: 1 = absence of decline; 2 = moderate decline; 3 = severe decline; 4 = total decline; and 5 = plant death. The total number of fruit, average fruit weight, and total fruit weight were evaluated at 18, 24, and 30 MAT. The stem diameter, plant height, and plant canopy width were evaluated at the full flowering stage (30 MAT).

**Statistical analysis**

The data on presence of eggs and juveniles in the soil and roots, average fruit weight (g), total number of fruit, total fruit weight (t ha$^{-1}$), stem diameter (mm), plant height (m), and plant canopy width (m) were subjected to analysis of variance using the GLM procedure of the SAS, considering each evaluation in a commercial farmer area as one block, resulting in a complete randomized block design. The data on eggs and juveniles of *M. enterolobii* were transformed to $\sqrt{X+1}$ before analysis of variance.

## Results and discussion

The propagation process had efficiency of 57%, with 680 of the 1,194 cuttings with shoots and roots in good vegetative conditions at 120 days after planting in the plastic bags.

***Psidium* hybrid resistant to *Meloidogyne enterolobii***

The presence of juveniles (nematode destructive phase) of *M. enterolobii* in the roots of the 30 hybrid plants of *P. guajava* × *P. guineense* was very low, and absent in 22 plants after five years (Table 1). Considering a period of about nine months for seedling development in the nursery, where infestation by this pathogen may occur, the hybrid showed high resistance throughout almost 6 years, attesting to its effectiveness in controlling this nematode.

Infestation by eggs and juveniles in the roots of the cv. Paluma significantly differed from infestation in the roots of the hybrid in the five evaluation times in joint evaluation, except at 6 months after transplanting (MAT). The highest infestation by juveniles in the roots occurred at 24 MAT, which was 370 times higher than the infestation at 6 MAT. The magnitude of the infestation in the cv. Paluma at 24 MAT was almost 540 times higher than the average infestation of the hybrid (Table 2).

The number of juveniles in the roots increased by a factor of 18 from the 6$^{th}$ to the 12$^{th}$ MAT, and decreased by a factor of 9 from the 24$^{th}$ to the 30$^{th}$ MAT. Some plants died, denoting that the 'Paluma' root system was completely destroyed (Table 2). The rootstock-scion interaction was not significant since the results for the root system of the hybrid grown singly and as rootstock for guava cultivars were similar.

The number of eggs and juveniles in the soil was almost zero, not differing among treatments at 6 MAT (Table 2). The number of juveniles in the soils were significant different at 12, 18, 24 and 30 MAT, with 'Paluma' sites presenting up to 29-fold higher than of the treatments with the hybrid as rootstock (Table 2). These results indicate a weak presence of the nematode in the evaluation sites at 6 MAT and the increasing of nematode population after guava establishment.

The average number of juveniles in the plant increased in the hybrid root system at each evaluation time, increasing nearly by a factor of 4 from the 24$^{th}$ to the 30$^{th}$ MAT, with means of 3 (6 MAT), 34 (12 MAT), 159 (18 MAT), 129 (24 MAT) and 489 (30 MAT) (Table 2). These results indicate a low juvenile population in the hybrid root system compared to the 69,183 juveniles found in the 'Paluma' root system at 24 MAT.

**Table 1.** Number of eggs and juveniles of *Meloidogyne enterolobii* in the soil and roots of 30 $F_1$-hybrid plants of *Psidium guajava* × *P. guineense*, evaluated five years after transplanting in the experimental field of Bebedouro, Petrolina, state of Pernambuco, Brazil.

| Plants | Number 10 g$^{-1}$ roots | | Number 100 g$^{-1}$ soil | |
|---|---|---|---|---|
| | Eggs | Juveniles | Eggs | Juveniles |
| PL 1 | 480 | 0 | 0 | 0 |
| PL 2 | 2,000 | 520 | 0 | 0 |
| PL 3 | 1,200 | 480 | 0 | 0 |
| PL 4 | - | - | 200 | 0 |
| PL 5 | 2,080 | 480 | 160 | 0 |
| PL 6 | 120 | 0 | 120 | 0 |
| PL 7 | 80 | 0 | 0 | 0 |
| PL 8 | 200 | 0 | 0 | 40 |
| PL 9 | 40 | 0 | 0 | 0 |
| PL 10 | 200 | 0 | 0 | 0 |
| PL 11 | 320 | 0 | 240 | 0 |
| PL 12 | 240 | 0 | 0 | 0 |
| PL 13 | 320 | 40 | 400 | 0 |
| PL 14 | 400 | 0 | 480 | 0 |
| PL 15 | 600 | 80 | 0 | 0 |
| PL 16 | 120 | 0 | 40 | 80 |
| PL 17 | 800 | 0 | 80 | 40 |
| PL 18 | 80 | 0 | 0 | 0 |
| PL 19 | 160 | 0 | 0 | 0 |
| PL 20 | 440 | 0 | 120 | 0 |
| PL 21 | 200 | 0 | 120 | 0 |
| PL 22 | 0 | 0 | 240 | 0 |
| PL 23 | 160 | 0 | 0 | 0 |
| PL 24 | 120 | 0 | 0 | 0 |
| PL 25 | 80 | 0 | 0 | 120 |
| PL 26 | 80 | 0 | 0 | 80 |
| PL 27 | 0 | 0 | 120 | 0 |
| PL 28 | 600 | 160 | 80 | 40 |
| PL 29 | 800 | 0 | 240 | 0 |
| PL 30 | 640 | 120 | 0 | 0 |

***Psidium* hybrid compatible as guava rootstock**

The yields of the three treatments, since the hybrid did not yield fruit, were not significantly different in the first harvest (18 MAT) (Table 3); thus, despite the more intense presence of the pathogen in 'Paluma' without grafting (Table 2), the nematode attack did not hinder initial fruit production. However, the effect of the nematode attack became apparent in the second harvest (24 MAT), when the mean total weight of fruit of the guava cultivars with the hybrid as rootstock was significantly different than the means of 'Paluma' without grafting (Table 3).

The averages of total number of fruit (TNF), mean fruit weight (MFW), and total fruit weight (TFW) differed significantly in the second and third harvests (Table 3). In the third harvest, the cultivars Pedro-Sato and Paluma grafted onto the hybrid had fruit yield of approximately 40 t ha$^{-1}$, with fruit production 10 times higher than that of 'Paluma' without grafting.

The averages of stem diameter (SD), plant height (PH), and plant canopy width (PCW) of the guava cultivars grafted onto the hybrid significantly differed from the averages

**Table 2.** Number of eggs (NE) and juveniles (NJ) of *Meloidogyne enterolobii* in the soil and roots (NEr and NJr); mean squares of the treatment (MST), residue (MSR), evaluation time (MSE) and [treatment × evaluation time] (MST×E); and coefficient of variation (CV) of the guava cv. Paluma (Paluma), hybrid *Psidium guajava* × *P. guineense* (Hybrid), Paluma grafted onto the hybrid *P. guajava* × *P. guineense* (H+Paluma), and cv. Pedro-Sato grafted onto the hybrid of *P. guajava* × *P. guineense* (H+PSato) over 30 months after transplanting (MAT), in production areas of the Nilo Coelho Irrigation Project, Petrolina, state of Pernambuco, Brazil. Data are mean values of 4 replicates ($n = 10$).

| Treatments | 6 MAT | | | | 12 MAT | | | | 18 MAT | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | NEs | NJs | NEr | NJr | NEs | NJs | NEr | NJr | NEs | NJs | NEr | NJr |
| Paluma | 2$^{A}$ | 2$^{A}$ | 1,184$^{A}$ | 180$^{A}$ | 4$^{A}$ | 143$^{A}$ | 8,506$^{A}$ | 3,308$^{A}$ | 3$^{A}$ | 126$^{A}$ | 8,870$^{A}$ | 4,104$^{A}$ |
| Hybrid | 0$^{A}$ | 8$^{A}$ | 26$^{B}$ | 0$^{B}$ | 0$^{A}$ | 5$^{B}$ | 24$^{B}$ | 5$^{B}$ | 1$^{A}$ | 3$^{B}$ | 214$^{B}$ | 125$^{B}$ |
| H+Paluma | 0$^{A}$ | 0$^{A}$ | 524$^{A}$ | 8$^{B}$ | 2$^{A}$ | 0$^{B}$ | 409$^{B}$ | 12$^{B}$ | 2$^{A}$ | 2$^{B}$ | 470$^{B}$ | 270$^{B}$ |
| H+PSato | 0$^{A}$ | 12$^{A}$ | 40$^{B}$ | 0$^{B}$ | 0$^{A}$ | 1$^{B}$ | 72$^{B}$ | 85$^{B}$ | 1$^{A}$ | 1$^{B}$ | 431$^{B}$ | 82$^{B}$ |
| MST | 0.4$^{NS}$ | 2.8$^{NS}$ | 1,793** | 917** | 0.8$^{NS}$ | 217** | 21,853** | 8,729** | 2.8$^{NS}$ | 220** | 15,652** | 7,667** |
| MSR | 0.4 | 4.5 | 244 | 23 | 1.2 | 21 | 851 | 329 | 1.2 | 16 | 921 | 400 |
| *CV* | *56* | *147* | *168* | *154* | *93* | *158* | *127* | *135* | *88* | *138* | *125* | *118* |
| Mean | 0.5 | 5.5 | 443 | 47 | 1.5 | 37 | 2,252 | 852 | 1.8 | 33 | 2,446 | 1,145 |
| | 24 MAT | | | | 30 MAT | | | | Joint analysis | | | |
| | NEs | NJs | NEr | NJr | NEs | NJs | NEr | NJr | NEs | NJs | NEr | NJr |
| Paluma | 16$^{A}$ | 98$^{A}$ | 10,459$^{A}$ | 69,183$^{A}$ | 16$^{A}$ | 172$^{A}$ | 7,858$^{A}$ | 6,584$^{A}$ | 7.8$^{A}$ | 108$^{A}$ | 7,375$^{A}$ | 16,672$^{A}$ |
| Hybrid | 3$^{B}$ | 2$^{B}$ | 392$^{B}$ | 60$^{B}$ | 4$^{A}$ | 0$^{B}$ | 403$^{B}$ | 182$^{B}$ | 1.6$^{A}$ | 3.6$^{B}$ | 212$^{B}$ | 74$^{B}$ |
| H+Paluma | 2$^{B}$ | 4$^{B}$ | 316$^{B}$ | 63$^{B}$ | 76$^{A}$ | 32$^{B}$ | 528 | 576$^{B}$ | 16.8$^{A}$ | 7.6$^{B}$ | 449$^{B}$ | 186$^{B}$ |
| H+PSato | 4$^{B}$ | 12$^{B}$ | 511$^{B}$ | 263$^{B}$ | 8$^{A}$ | 36$^{B}$ | 888$^{B}$ | 710$^{B}$ | 2.6$^{A}$ | 12$^{B}$ | 348$^{B}$ | 228$^{B}$ |
| 6 MAT | - | - | - | - | - | - | - | - | 0.5$^{B}$ | 6$^{B}$ | 443$^{B}$ | 47$^{B}$ |
| 12 MAT | - | - | - | - | - | - | - | - | 1.5$^{B}$ | 37$^{AB}$ | 2,253$^{AB}$ | 853$^{B}$ |
| 18 MAT | - | - | - | - | - | - | - | - | 2.0$^{B}$ | 33$^{AB}$ | 2,446$^{AB}$ | 1,145$^{B}$ |
| 24 MAT | - | - | - | - | - | - | - | - | 6.3$^{B}$ | 29$^{AB}$ | 2,920$^{A}$ | 17,392$^{A}$ |
| 30 MAT | - | - | - | - | - | - | - | - | 26$^{A}$ | 60$^{A}$ | 2,419$^{AB}$ | 2,019$^{B}$ |
| MST (T) | 13* | 138** | 29,648** | 148,060** | 21$^{NS}$ | 259** | 24,015** | 16,852** | 12$^{NS}$ | 633** | 81,742** | 10,1320** |
| MSE (E) | - | - | - | - | - | - | - | - | 22** | 73 | 6,851 | 24,903 |
| MST*E | - | - | - | - | - | - | - | - | 156 | 51 | 2,827 | 20,073 |
| MSR | 3.6 | 16 | 819 | 8,483 | 21 | 35 | 386 | 575 | 5.7 | 19 | 721 | 2,210 |
| *CV* | *104* | *137* | *91* | *185* | *198* | *143* | *61* | *92* | *156* | *152* | *112* | *215* |
| Mean | 6.3 | 29 | 2,919 | 17,392 | 26 | 60 | 2,419 | 2,013 | - | - | - | - |

Means followed by the same letter in the columns do not differ by Tukey's test at 5% probability. *: significant at 5%, **: significant at 1%, and $^{NS}$: not significant at 5% probability by the F test.

**Table 3.** Total number of fruit (TNF), mean fruit weight (MFW), and total fruit weight (TFW) in each of three harvests; stem diameter (SD), plant height (PH), and plant canopy width (PCW) at 30 months after transplanting; mean squares of treatment (MST) and residue (MSR); and coefficient of variation (CV) of the guava cv. Paluma, 'Paluma' grafted onto the hybrid *Psidium guajava* × *P. guineense* (H+Paluma), and cv. Pedro-Sato grafted onto the hybrid of *P. guajava* × *P. guineense* (H+PSato) in production areas of the Nilo Coelho Irrigation Project, Petrolina, state of Pernambuco, Brazil. Data are mean values of 4 replicates ($n = 10$).

| Treatments | Harvests | | | | | | | | | SD (mm) | PH (m) | PCW (m) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | First | | | Second | | | Third | | | | | |
| | TNF | MFW (kg) | TFW (t ha$^{-1}$) | TNF | MFW (kg) | TFW (t ha$^{-1}$) | TNF | MFW (kg) | TFW (t ha$^{-1}$) | | | |
| Paluma | 34$^{A}$ | 0.22$^{A}$ | 6.0$^{A}$ | 33$^{B}$ | 0.22$^{B}$ | 6.5$^{B}$ | 32$^{B}$ | 0.15$^{C}$ | 4.5$^{B}$ | 42$^{B}$ | 1.6$^{B}$ | 1.7$^{B}$ |
| H+Paluma | 29$^{A}$ | 0.25$^{A}$ | 6.2$^{A}$ | 59$^{A}$ | 0.24$^{A}$ | 14.0$^{A}$ | 155$^{A}$ | 0.24$^{A}$ | 42.1$^{A}$ | 55$^{A}$ | 2.2$^{A}$ | 2.3$^{A}$ |
| H+PSato | 37$^{A}$ | 0.22$^{A}$ | 6.2$^{A}$ | 72$^{A}$ | 0.20$^{B}$ | 13.8$^{A}$ | 191$^{A}$ | 0.21$^{B}$ | 43.6$^{A}$ | 55$^{A}$ | 2.2$^{A}$ | 2.3$^{A}$ |
| MST | 275$^{NS}$ | 0.005$^{NS}$ | 0.37$^{NS}$ | 5,610** | 0.008* | 201** | 108,080** | 0.031** | 5,827** | 916** | 1.96** | 2.1** |
| MSR | 398 | 0.004 | 10 | 581 | 0.002 | 22.9 | 3,242 | 0.0005 | 147 | 108 | 0.1 | 0.18 |
| CV | 60 | 30 | 52 | 43 | 20 | 41 | 45 | 11 | 44 | 20 | 16 | 20 |
| Mean | 33 | 0.22 | 6.1 | 56 | 0.22 | 12.0 | 126 | 0.20 | 27.2 | 51 | 2.0 | 2.1 |

Means followed by the same letter in the columns do not differ by the SNK test at 5% probability. *: significant at 5%, **: significant at 1%, and $^{NS}$: not significant at 5% probability by the F test.

of the cv. Paluma without grafting at 30 MAT (Table 3), indicating that one of the main visual effects of the nematode in susceptible plants is reduction in plant size. The SD above and below the grafting region in the cultivars Paluma or Pedro-Sato grafted onto the hybrid was not compared, since the junction region could not be identified due to the excellent bond between the species. These results denote the high compatibility of the hybrid as rootstock for the guava cultivars, since no exudation or cracking occurred in the stem of these grafted plants.

Only one of the 45 plants grafted onto the hybrid showed decline (moderate), whereas 15 'Paluma' plants without grafting showed decline (from severe to total decline), and two of these plants died. These results also denote the resistance of the hybrid *P. guajava* × *P. guineense* to the nematode, since the presence of nematode eggs and juveniles in roots of the hybrid plants (Table 2) did not affect the yield in the commercial guava orchards (Table 3); the plants showed practically no symptoms of guava decline, burning of leaf edges, yellowing of leaves and leaf drop.

*Meloidogyne enterolobii* causes progressive rotting of the plant root system, burning of leaf edges, yellowing of leaves, and leaf drop, resulting in plant death (Gomes *et al.*, 2011). The initial direct effect of this nematode on guava crops caused losses of about US$ 70 million and about 4,000 jobs in Brazil by 2009 (Pereira *et al.*, 2009). This is the first study to report the effective genetic control of *M. enterolobii*, a guava nematode of worldwide importance, based on a *Psidium* hybrid resistant rootstock, developed with this ultimate goal.

According to Freitas *et al.* (2014) *P. cattleianum* (yellow guava), *P. friedrichsthalianum*, (Costa Rican guava), and *P. rufum* (purple guava) were resistant to *Meloidogyne* spp. and when used as rootstocks under greenhouse conditions, *P. cattleianum* and *P. friedrichsthalianum* were compatible with 'Paluma' and in greenhouse and field conditions only 50% of both scions survived. To date, the cited authors do

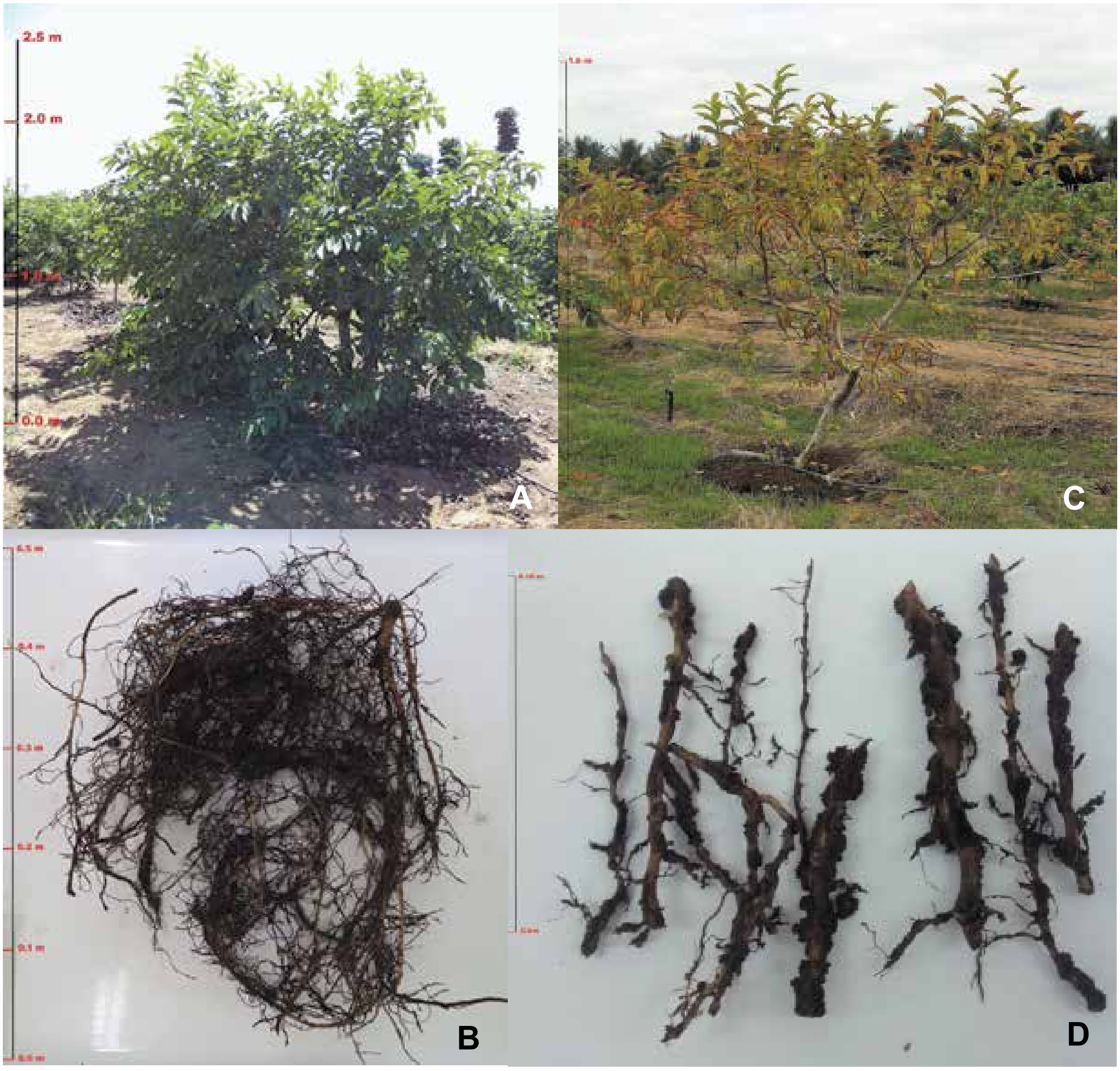


**Figure 1.** Vegetative aspects of the aerial (A) and root system (B) of the cultivar Paluma grafted onto the hybrid *Psidium guajava* × *P. guineense* at 30 months old; and vegetative aspects of the aerial (C) and root system (D) of the cultivar Paluma without grafting, at 30 months old, showing symptoms of guava decline and galls in the root system caused by *Meloidogyne enterolobii*.

not mention evaluation of fruit production.

Bogantes-Arias and Newcomer (2010) also reported that the *M. enterolobii* was unable to colonize the roots of *P. friedrichsthalianum*. When *P. friedrichsthalianum* was used as rootstock of 'R9-33' guava the mentioned authors reported higher fruit number and weight in guava without *P. friedrichsthalianum* rootstock, compared with 'R9-33' grafted in this wild *Psidium*, at 250–300 days after transplanting. According to Bogantes-Arias and Newcomer (2010) nematode presence was very high in guava root system and absent in two wild *Psidium*. Our study evaluated the guava fruit yield for almost 900 days, making possible to infer about the compatibility with two major Brazilian guava cultivars.

The protocol adopted to propagate the *Psidium* hybrid had results close to 60% reported by Zietemann and Roberto (2007) for the cv. Paluma using 1,500 mg $L^{-1}$ of IBA solution. This indicates that propagation on a commercial scale will not be a problem. According to Andrade and Martins (2003), exogenous application of indolebutyric acid promotes the rooting of cuttings of guava and other species, which show positive responses in size, weight, and early formation of roots. According to Martins and Hojo (2009), guava cuttings must be maintained in the substrate at least 60 days. Then the best cuttings must be transferred to polyethylene bags with commercial substrate or autoclaved soil.

The *Psidium* hybrid obtained yield of 40 t $ha^{-1}$ 30 months after transplanting, which is close to the guava yield reported in commercial orchards with excellent agronomic management. According to Agrianual (2016), the expected normal fruit yield for the Paluma cultivar at 3 years after planting, including irrigated and non-irrigated orchards, is approximately 16 t $ha^{-1}$, which is much lower than that found in the present study for the cv. Paluma grafted onto the hybrid. Farmers have reported 'Paluma' fruit yield around 40 t $ha^{-1}$, in healthy irrigated guava orchards in Petrolina, Brazil, with which is close to reported by us, using the *Psidium* hybrid as rootstock of 'Paluma'. Studies carried out in commercial orchards by Souza *et al.* (2006) and Gomes (2007) indicate that declining orchards show a 30% to 70% decrease in yield depending on crop management practices and products with action antagonistic to the nematode.

## Conclusion

These data on nematode behavior, fruit yield, and the vegetative state of guava plants (Figure 1) indicate the high resistance of the *Psidium* hybrid to *Meloidogyne enterolobii* and its good compatibility as rootstock for guava cultivars. Therefore, this hybrid is an alternative in management practices for preventing damage caused by the nematode in guava producing areas, with no additional costs or harm to the environment, such as the use of pesticides.

The hybrid *P. guajava* × *P. guineense* was registered and protected in the Brazilian Ministry of Agriculture, Livestock and Food Supply under the name BRS Guaraçá, allowing producers to multiply and commercialize this product as a nematode control measure in guava.

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