https://doi.org/10.71252/2177-34912026730016
ISSN: 2177-3491

Reaction of sugarcane (*Saccharum* spp.) cultivars to the root-knot nematode[1]

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ABSTRACT

Plant-parasitic nematodes are soil pathogens capable of causing significant damage in cultivated areas and are considered of economic importance for sugarcane production. Thus, the objective of this study was to evaluate the reaction of sugarcane (*Saccharum* spp.) cultivars to root-knot nematode (*Meloidogyne javanica*) parasitism. The cultivar reaction assay was conducted with four new cultivars registered by the UFSM breeding program, namely UFSM XIKA FW, UFSM LUCI FW, UFSM PRETA FW, and UFSM DINA FW, under two nematode treatments (with and without nematodes) in 2023 and repeated in 2024. The cultivars were inoculated with 5000 eggs + J2 of *Meloidogyne javanica*, and vegetative development variables, final nematode population in the root system, and reproduction factor (RF) were evaluated. All cultivars were resistant to nematode parasitism, showing a reproduction factor lower than 1.0.

Keywords: population frequency, survey, *Meloidogyne javanica*, resistance, control.

[1] Project derived from part of a final course project.

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Submitted: December 31st, 2025.
Accepted: August 3rd, 2026.

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INTRODUCTION

Sugarcane (*Saccharum* spp.) is one of the most important grasses for the Brazilian economy. The crop is widespread throughout almost the entire national territory and has been considered economically important since the colonial period.[1] According to the National Supply Company (CONAB), in the 2024/25 harvest, Brazil produced more than 689 million tons of sugarcane, with the Southeast region accounting for over 60 % of production, and the South region ranking fourth, with over 35 million tons.[2]

Although yield data are significant and future prospects are positive, sugarcane cultivation suffers from the parasitism of different species of plant-parasitic nematodes, which are found in all sugarcane-growing regions.[3]

Nematodes of the genera *Meloidogyne* Goeldi (1887) and *Pratylenchus* Filipjev (1936) are the main pests causing damage to the crop.[4,5] In sugarcane fields in Rio Grande do Sul, Gomes et al.[6] reported the widespread occurrence of *Meloidogyne* spp. and *Pratylenchus* spp., often with *M. javanica*, *M. incognita*, and *P. zeae* infesting the same area.

These pathogens attack the plant's root system and easily establish in cropping systems, mainly because sugarcane management relies on monoculture and straw removal.[7,8] Symptoms of parasitism are also reflected in the aerial parts of the plant, which may show wilting and yellowing, due to changes in the roots that impair water and nutrient absorption from the soil.[9] This scenario negatively affects yield, which can drop by approximately 20 to 40 % in plant cane.[10]

Nematode control in sugarcane is complex, and once these species are established in the field, eradication becomes virtually impossible. Therefore, information on the population dynamics of plant-parasitic nematodes in sugarcane fields, as well as knowledge of the species present in production areas, is crucial for proper management.[11] Frequent recommendations include crop rotation with non-host or poor-host plants, the use of resistant genotypes, and chemical and biological control measures.[12]

Genetic resistance to nematodes is one of the most efficient, cost-effective, and environmentally friendly control methods.[13] However, in sugarcane cultivation, chemical control is still the most widely adopted method by growers, through the application of nematicides at planting or in ratoon crops, due to the limited availability of nematode-resistant cultivars.[8] Thus, the objective of this study was to evaluate the reaction of sugarcane (*Saccharum* spp.) cultivars to root-knot nematode (*Meloidogyne javanica*) parasitism.

MATERIAL AND METHODS

To evaluate cultivar reactions, two greenhouse trials were conducted. The first trial, in 2023 (Trial I), lasted 50 days, and the second, in 2024 (Trial II), lasted 75 days. The procedures and evaluations were the same in both trials, except for the number of galls, which was assessed only in Trial II.

A sample of the *Meloidogyne javanica* inoculum used was kindly provided by the company Agronema and maintained in the nematode collection of the Phytopathology and Nematology Laboratory on "tomato (*Solanum lycopersicum*) "cultivar Santa Cruz" until the time of inoculation. Inoculation was carried out by processing tomato roots according to the method of Hussey and Barker,[14] modified by Bonetti and Ferraz.[15] Each plant was inoculated with 5.000 eggs plus eventual J2 juveniles.

The cultivars UFSM XIKA FW, UFSM LUCI FW, UFSM PRETA FW, and UFSM DINA FW were evaluated. All were commercially released by the Federal University of Santa Maria campus Frederico Westphalen (UFSM/FW) breeding program, registered with the Ministry of Agriculture, and suitable for production in areas with lower temperatures.[16] The cultivars were obtained in partnership with the Plant Biometry Laboratory of UFSM/FW.

The experiment was conducted in a completely randomized design, in a factorial scheme (4 × 2), with four sugarcane cultivars and two nematode levels (with and without nematodes), with six replicates per treatment (n = 6). Each replicate consisted of one plant.

For the production of seedlings, sugarcane stalks from each cultivar were collected in the field, and the buds were planted in 5 L pots containing a previously autoclaved mixture of soil, sand, and substrate in a 2:1:1 ratio. The seedlings were fertilized according to soil analysis and technical recommendations for the crop, and manual irrigation was performed twice a day. The pots were maintained according to the initial randomization on benches in a greenhouse, with temperatures ranging from 25 to 30 °C during the course of the experiments. Inoculation was carried out approximately 90 days after sprouting.

At the end of each trial, Fresh Mass (FM) and Dry Mass (DM) of the aerial part, as well as Root Mass (RM), were assessed. The Number of Galls (NG) per plant was also recorded. Roots were processed following the Hussey and Barker,[14] method, modified by Bonetti and Ferraz,[15] to determine the Final Root Population (FRP) and calculate the Reproduction Factor (RF = final

population / initial population). Cultivar reactions were classified as: RF > 1 = susceptible, RF < 1 = resistant, and RF = 0.00 = immune.[17] Additionally, a 250 cm³ soil sample was taken from each pot for nematode population counting.[18]

Data from the trials were analyzed separately and subjected to tests of normality (Shapiro–Wilk, $p < 0.05$) and homogeneity of variances (Bartlett's test, $p < 0.05$). Since the assumptions were not met, the data were transformed using $\sqrt{(x + 0.5)}$. The variables were subjected to analysis of variance, and when significant, means were compared using the Scott-Knott,[19] test at the 5% probability level, using Sisvar® software,[20] with results presented on the original scale.

RESULTS AND DISCUSSION

All sugarcane cultivars showed resistance to *Meloidogyne javanica* parasitism in the two evaluated trials (Table 1). Resistance was assessed using the Reproduction Factor (RF) proposed by Oostenbrink,[17] which allows the total count of nematodes in the roots, since visible gall formation does not always occur in sugarcane.[3,21,22] This was observed in Trial I, where galls were inconspicuous. The RF values for tomato plants cv. Santa Cruz (*Solanum lycopersicum*) were 11.65 and 11.11 for Trial I and II, respectively, confirming that the inoculum was viable.

The results obtained (Table 1) confirmed the resistance of the sugarcane materials cultivated in the experimental area. However, when analyzing the evaluated variables, differences were observed between the two trials conducted. In Trial I, galls were inconspicuous, similarly to what was reported by Marques.[23] In Trial II, galls were visibly present; however, the number of galls (NG) did not differ among cultivars, ranging from 274 to 388. These values are lower than those reported by Bellé,[21] who observed NG values ranging from 525 to 1.906, with statistically significant differences among the evaluated sugarcane genotypes.

The occurrence of galls does not necessarily indicate that a cultivar is susceptible to the nematode, since nematode reproduction and an RF greater than 1 require the formation of a feeding site in the root system, known as a coenocyte. This feeding site may occur independently of gall formation, just as galls may form without the establishment of a coenocyte, as observed in the present study. This indicates that although nematodes penetrated the roots and induced gall formation, they encountered difficulty in reproducing.[24] Therefore, cultivar resistance to parasitism may be attributed to this response, as even with cellular hypersensitivity and gall formation, the establishment of the feeding site may have been inhibited.[25]

Table 1. Mean values from Trials I and II of Soil Population (250 cm³), Final Root Population (FRP), Reproduction Factor (RF), and Reaction of Sugarcane (*Saccharum* spp.) Cultivars to *Meloidogyne javanica* parasitism

Trial I					
Cultivars	**NG[2]**	**Population**		**RF**	**Reaction**
		Soil (250 cm³)	**FRP**		
UFSM XIKA FW	---	$300.00^{7.24}$ b	$116.66^{0.92}$ b	$0.02^{0.0028}$ b	R
UFSM LUCI FW	---	$1.400,00^{15.03}$ a	$220.83^{6.06}$ a	$0.04^{0.0293}$ a	R
UFSM PRETA FW	---	$400.00^{7.78}$ b	$187.50^{2.54}$ a	$0.03^{0.0097}$ a	R
UFSM DINA FW	---	$537.50^{9.77}$ b	$200.00^{2.30}$ a	$0.04^{0.0083}$ a	R
Tomato[1]			58.225,00	11.65	S
CV		43.6	24.2	1.83	
Trial II					
Cultivars	**NG**	**Population**		**RF**	**Reaction**
		Soil (250 cm³)	**FRP**		
UFSM XIKA FW	$295.50^{1.34}$ a	$93.33^{10.21}$ a	$713.33^{0.07}$ b	$0.161^{2.17}$ b	R
UFSM LUCI FW	$274.16^{4.68}$ a	$193.33^{20.06}$ a	$2.933,33^{0.22}$ a	$0.625^{2.82}$ a	R
UFSM PRETA FW	$287.16^{2.04}$ a	$50.00^{12.36}$ a	$1.056,66^{0.09}$ b	$0.221^{3.51}$ b	R
UFSM DINA FW	$388.33^{5.88}$ a	$116.66^{16.87}$ a	$2.373,33^{0.16}$ a	$0.498^{2.78}$ a	R
Tomato[1]	215.00		55.560,00	11.11	S
CV	18.02	41.14	39.91	14.52	

Means followed by the same letter in the column do not differ significantly by the Scott-Knott mean grouping test at 5% probability ($p < 0.05$). Numbers raised to the exponent represent the standard deviation. NG = Number of Galls; FRP = Final Root Population (eggs + J2); RF = Reproduction Factor; R = Resistant; S = Susceptible; [1] Tomato cultivar Santa Cruz – Susceptible control. [2] Variable evaluated only in Trial II

Regarding the nematode populations detected in 250 cm³ of soil, variation in the number of individuals was observed between the two trials. The highest soil population was recorded in Trial I, with the cultivar UFSM LUCI FW presenting the highest population (1.400), differing from the other cultivars. This may be associated with a greater ease of nematode multiplication in this cultivar.

In Trial II, soil populations were lower and similar among the cultivars, with no significant differences observed. The presence of eggs and juveniles of *M. javanica* in the soil is related to the biology of this species, which, although it is a sedentary endoparasite, exhibits external oviposition. Egg masses may detach from the roots, and the second-stage juveniles (J2), which hatch from these eggs, represent a mobile phase in the soil that is essential for the infection of new plants.[26]

In both trials, cultivar resistance was evidenced by RF values lower than 1.0 (Table 1), indicating the absence of nematode multiplication in the evaluated cultivars. Thus, these cultivars may be recommended for use in crop rotation or succession systems aimed at reducing the population of this pathogen.

Nevertheless, different levels of resistance among cultivars were observed in each trial (Table 1). In Trial I, the cultivar UFSM XIKA FW exhibited a significantly higher level of resistance than the others, with lower final root population (FRP = 116.00) and RF (0.02) values. In Trial II, FRP and RF values were numerically higher than those observed in Trial I; however, RF remained below 1.0. Under these conditions, the cultivars UFSM XIKA FW and UFSM PRETA FW showed similar and superior resistance compared with the other cultivars, presenting FRP (eggs + juveniles) values of 713.00 and 1.056, respectively. These values are lower than those reported by Dinardo-Miranda et al.,[27] who evaluated sugarcane cultivars from the CTC, IAC, and RB groups in an area previously infested with *M. javanica* and observed nematode populations ranging from 15 to 2.510 second-stage juveniles per 50 g of roots.

Resistance of sugarcane genotypes to *M. javanica* has also been reported by other authors. Martinha et al.,[28] when evaluating the sugarcane genotypes RB036059 and RB046209, reported RF values of 0.62 and 0.49, respectively, which are similar to those observed in this study for the cultivars UFSM LUCI FW and UFSM DINA FW in Trial II.

Contrasting results were reported by Dias-Arieira et al.,[29] who evaluated cultivars from the RB and CTC groups and classified them as immune (RF = 0.0) or susceptible (RF > 1.0) to *M. javanica* parasitism. Similarly, Santos,[22] after conducting an experiment with sugarcane cultivars 60 days after inoculation, found that eight cultivars from the CTC group (CTC 11, CTC 12, CTC 13, CTC 14, CTC 15, CTC 16, CTC 17, and CTC 18) were susceptible to *M. javanica*, with RF values ranging from 1.0 to 1.80.

In a study by Bellé,[21] different genotypes from the RB group were evaluated for their reaction to *M. javanica*, and RF values ranged from 7.93 to 36.77, confirming their susceptibility. The same author emphasized the limited availability of nematode-resistant materials and reported that the presence of *M. javanica* may render sugarcane cultivation areas unviable.

Additionally, Barbosa et al.,[30] when evaluating the susceptibility of the cultivar SP911049 to *M. javanica* and *M. incognita*, observed that the final population of *M. javanica* in plant roots reached 16.625 individuals, whereas *M. incognita* reached 352.800 individuals, with RF values of 4.16 and 88.20 for the two species, respectively, indicating high susceptibility of the material.

Some sugarcane cultivars have shown resistance to other *Meloidogyne* spp. species. Silva et al.,[3] and Marques,[23] when evaluating the reaction of the cultivars RB92579 and RB867515 to *M. enterolobii* 90 days after inoculation with 5.000 eggs, reported RF values of 0.00 and 0.04, respectively, according to Silva et al.,[3] and RF values of 4.75 and 1.89, respectively, according to Marques.[23]

Analysis of RF values obtained in both trials (Table 1) revealed numerical differences, which may be attributed to the longer duration of Trial II and to environmental conditions. Although both experiments were conducted under greenhouse conditions, environmental variables differed between trials, and it is well established that the same cultivar may exhibit different responses to a pathogen when exposed to different environments.[12]

The interference of *M. javanica* infection on the development of sugarcane cultivars in both trials is presented in Table 2. In Trial I, cultivars did not differ from each other in terms of fresh mass (FM), regardless of the presence or absence of the root-knot nematode. However, a significant difference was observed for dry mass (DM), in which the presence of the pathogen negatively affected the development of the cultivar UFSM DINA FW compared with the other cultivars, resulting in a reduction in DM greater than 70 % relative to the others. Differences were also observed for root mass (RM) in the absence of nematode inoculation, with the cultivar UFSM PRETA FW presenting a root mass of 35.83 g.

There are few studies comparing the development of sugarcane plants in the presence and absence of nematodes. However, some authors, when evaluating the genotype RB867515 under parasitism by *M. incognita*, *M. javanica*, and *M. arenaria*, observed shoot fresh mass values of 1.19 g, 1.48 g, and 1.35 g, respectively, which differed statistically from 3.85 g in plants not inoculated with any nematode species.[31] The authors concluded that all tested species negatively affected the development of the cultivar. Similarly, Santos[22] observed that the varieties CTC 11, CTC 12, and CTC 13 differed from the other evaluated cultivars and presented shoot dry mass (SDM) values of 10.37 g, 7.30 g, and 6.83 g, respectively, when inoculated with *M. javanica*. A comparable finding was reported by Gomes, Bellé, and Porto,[6] who evaluated shoot biomass of sugarcane fields in Rio Grande do Sul infested by *Meloidogyne* spp. and observed reductions in plant growth.

The cultivars evaluated in Trial I also showed differences in dry mass (DM) in the absence of nematodes, with the cultivar UFSM PRETA FW exhibiting the greatest vegetative growth and, consequently, the highest DM (52.88 g), differing statistically from the other cultivars, which showed similar development (Table 2). These results are related to the genetic background of the materials, since the expression of traits such as plant architecture, height, and stalk diameter is associated with climate and management practices,[32] and may vary among cultivars, as observed under nematode-free conditions.

When analyzing root mass (RM) in Trial I (Table 2), the cultivar UFSM XIKA FW differed from the others by presenting the lowest RM value (21.93 g) in the absence of nematode inoculation, with no differences observed in root growth of this cultivar in the presence of the nematode. Conversely, the cultivar UFSM PRETA FW differed with respect to nematode presence, showing reduced RM when not inoculated (35.83 g). Numerically, RM values under nematode inoculation were higher for all evaluated cultivars compared with non-inoculated plants; however, no statistical differences were observed among cultivars. In contrast, Santos[22] reported statistically significant

Table 2. Means from Trials I and II of fresh aerial biomass (FM/g), dry aerial biomass (DM/g), and fresh root biomass (RM/g) of cultivars with and without nematode

Cultivars	Trial I		Trial II	
	Fresh Mass			
	Wi/N	Wo/N	Wi/N	Wo/N
UFSM XIKA FW	$60.65^{0.62}$ Aa	$73.08^{0.76}$ Aa	$38.86^{0.22}$ Aa	$40.60^{0.69}$ Aa
UFSM LUCI FW	$71.13^{1.18}$ Aa	$67.08^{0.53}$ Aa	$31.68^{0.58}$ Aa	$37.15^{1.18}$ Aa
UFSM PRETA FW	$66.20^{0.53}$ Aa	$82.93^{0.79}$ Aa	$37.85^{1.21}$ Aa	$21.71^{0.34}$ Bb
UFSM DINA FW	$61.93^{0.58}$ Aa	$73.90^{0.99}$ Aa	$49.15^{0.88}$ Aa	$42.08^{0.73}$ Aa
CV	12.65		14.64	
Cultivars	**Trial I**		**Trial II**	
	Dry Mass			
	Wi/N	Wo/N	Wi/N	Wo/N
UFSM XIKA FW	$38.16^{0.46}$ Aa	$39.60^{0.77}$ Ab	$18.28^{0.14}$ Aa	$19.10^{0.46}$ Aa
UFSM LUCI FW	$37.75^{0.33}$ Aa	$38.08^{0.76}$ Ab	$14.30^{0.24}$ Aa	$18.35^{0.79}$ Aa
UFSM PRETA FW	$45.83^{0.77}$ Aa	$52.88^{0.44}$ Aa	$16.33^{0.72}$ Aa	$12.21^{0.44}$ Aa
UFSM DINA FW	$28.48^{0.63}$ Bb	$43.75^{0.99}$ Ab	$21.73^{0.64}$ Aa	$19.06^{0.57}$ Aa
CV	11.79		13.85	
Cultivars	**Trial I**		**Trial II**	
	Root Mass			
	Wi/N	Wo/N	Wi/N	Wo/N
UFSM XIKA FW	$35.95^{0.48}$ Aa	$21.93^{0.63}$ Ab	$48.53^{0.93}$ Aa	$58.13^{1.17}$ Aa
UFSM LUCI FW	$32.83^{0.89}$ Aa	$31.70^{0.97}$ Aa	$39.91^{0.70}$ Aa	$46.16^{0.84}$ Aa
UFSM PRETA FW	$58.06^{1.38}$ Aa	$35.83^{0.73}$ Ba	$33.86^{0.51}$ Aa	$43.56^{0.43}$ Aa
UFSM DINA FW	$43.60^{1.62}$ Aa	$40.65^{1.12}$ Aa	$42.75^{1.64}$ Aa	$30.41^{0.92}$ Ab
CV	22.07		16.57	

Means followed by the same uppercase letter in the rows do not differ between with and without nematode, and means followed by the same lowercase letter in the columns do not differ among cultivars by the Scott-Knott mean grouping test at 5% probability. Numbers raised to the exponent represent the standard deviation. Wi/N = With Nematode; Wo/N = Without Nematodes.

differences in root mass among CTC group cultivars inoculated with *M. javanica*, with values ranging from 14.72 g to 23.50 g.

In Trial II, the cultivar × nematode interaction was significant only for the variables fresh mass (FM) and root mass (RM). The presence of the root-knot nematode did not significantly interfere with vegetative development of the cultivars. However, in the absence of inoculation, the cultivar UFSM PRETA FW exhibited lower FM compared with inoculated plants, as well as in comparison with the other evaluated cultivars.

These results contrast with those reported by Barbosa,[33] who observed no statistical difference in the cultivar RB968515 when inoculated with *M. javanica* compared with the non-inoculated control, with shoot fresh mass values of 268.30 g and 242.07 g, respectively. Conversely, Silva et al.[3] observed significant differences in shoot fresh mass and root weight for the cultivars RB92579, RB863129, RB813250, and RB867515 when inoculated with *M. incognita*.

In an experiment conducted by Silva,[34] evaluating the reaction of 25 sugarcane genotypes to *M. javanica* parasitism, the genotypes RB071055, RB071096, RB041593, RB041595, RB041596, and RB061315 exhibited the lowest shoot biomass values, did not differ among themselves, and differed significantly from the susceptible genotype.

Regarding RM, the sugarcane cultivars showed similar values regardless of the presence or absence of the pathogen (Table 2). However, when comparing non-inoculated cultivars, only UFSM DINA FW differed from the others, presenting the lowest RM value (30.41 g), which may be attributed to the genetic characteristics of the material. These results differ from those reported by Barbosa,[33] who evaluated the reaction of the cultivar RB96710 to *M. javanica* and observed statistically significant differences in root weight between plants inoculated with 20.000 eggs and the non-inoculated control, with values of 119.93 g and 109.60 g, respectively.

The reduced development of cultivars in the absence of nematodes may be attributed to meteorological conditions during the experiments. It is well known that sugarcane metabolism is reduced when temperatures exceed 38 to 40 °C,[35] values that were recorded under greenhouse conditions during the trials. In addition, Knapp,[16] when evaluating productive parameters of the same cultivars used in the present study across different municipalities in the state of Rio Grande do Sul, observed significant variation among cultivars for the trait stalk diameter.

CONCLUSIONS

The evaluated cultivars showed resistance to parasitism by the *Meloidogyne javanica* isolate tested under greenhouse conditions. However, further studies are necessary to assess the reaction of these cultivars under different field environments and against other species of plant-parasitic nematodes

ACKNOWLEDGMENTS, FINANCIAL SUPPORT AND FULL DISCLOSURE

The authors thank the Federal University of Santa Maria for providing materials and resources and report that the project did not receive financial support during its execution. The authors also declare that there are no conflicts of interest in the conduct and publication of this work.

DATA AVAILABILITY STATEMENT

All datasets supporting the findings of this study are included in this article.

AUTHOR CONTRIBUTIONS

Conceptualization: Júlio de Cezaro Piovesan, Stela Maris Kulczynski.

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