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Analysis of growth, yield and control of *Cophes notaticeps* and *Polyphagotarsonemus latus* in *Jatropha curcas* plants under different doses of silicon

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Abstract: The present study aims to evaluate the effects of Si on growth, yield and resistance of *Jatropha curcas* plants to *Cophes notaticeps* and *Polyphagotarsonemus latus*. The study was carried out in two consecutive years with *J. curcas* plants with 3 years old in 3x2 m spacing. The assays were set up with randomized complete block design with five concentrations (0, 10, 20, 40 and 80 mM L^{-1}) and five replications. It was set up another experiment in a greenhouse following completely randomized factorial design 5x2 with five silicon concentrations (0, 10, 20, 40 and 80 mM L^{-1}) and two water supply: daily irrigation with water volumes according to 50% and 100% of evapotranspiration, six replications and one plant per plot. The present study allows clarifying that *J. curcas* plants are non-accumulating plants, for accumulating less than 1% of silicon in the leaves. The low accumulation of silicon in the leaves did not significantly inferred in growth of *J. curcas*, however, the reduction of specific leaf area possibly occurred by the formation of a thin silica layer and reduced the yield by the decrease sunlight absorption. The silicon did not mitigated the damages by *Cophes notaticeps* and *Polyphagotarsonemus latus* by the low ability of the plant to accumulate silicon, however, is possible to affirm that the injuries severity by *Cophes notaticeps* is proportional to stem diameter.

Key words: Mineral nutrition, biotic stress, biofuel, elicitor.

Análise de crescimento, produtividade e controle de *Cophes notaticeps e Polyphagotarsonemus latus* em plantas de *Jatropha curcas* Submetidas a diferentes doses de silício

Resumo: O presente estudo teve como objetivo avaliar os efeitos do Si no crescimento, produtividade e resistência de plantas de *Jatropha curcas* a *Cophes notaticeps e Polyphagotarsonemus latus*. O trabalho foi conduzido em dois anos consecutivos em plantas de *J. curcas* com três anos de idade em espaçamento de 3 x 2 m em campo. Os ensaios foram montados seguindo o delineamento em blocos casualizados com cinco doses de silício (0; 10; 20; 40 e 80 mM L^{-1}) e cinco repetições. Foi também montado um ensaio em casa de vegetação seguindo o delineamento inteiramente casualizado em arranjo fatorial 5 x 2 com cinco níveis de Si: (0; 10; 20; 40 e 80 mM L^{-1}) e dois tratamentos de suprimento hídrico: irrigação diária com volumes de água referentes a 50% e 100% da evapotranspiração, seis repetições e parcela de uma planta. O presente estudo permite classificar as plantas de *J. curcas* como não acumuladoras de silício por conterem menos de 1% deste nutriente nas folhas. O baixo acúmulo de silício nas folhas não interferiu significativamente no crescimento vegetativo de *J. curcas*, no entanto, as reduções na área foliar específica possivelmente pela formação da delgada camada sílica reduziu a produtividade pelo incremento da extinção da radiação solar. O silício não mitigou os danos causados por *Cophes notaticeps* e *Polyphagotarsonemus latus* pela baixa capacidade da planta acumular silício na folha, no entanto, é possível afirmar que a severidade da injúria causada por *Cophes notaticeps* é proporcional ao diâmetro do caule.

Palavras-chave: Nutrição mineral, estresse biótico, biocombustível, elicitor.

Introduction

The National Program of Production and Use of Biodiesel (Programa Nacional de Produção e Uso de Biodiesel - PNPB) expanded the biofuel production in Brazil so that in 2018 it was produced 5.35 billion liters to attend the mandatory additional of 11% of biofuel (B11) in petrodiesel. The volume supported to produce this year was around 21 billions liters (Anp, 2019).

For greater security in production chain and wealth generation in many different states, the vegetal oil production in PNPB cannot be supported just by one raw material, thus, is necessary to diversify the resources from the use of others oilseeds crops like *Jatropha curcas* L. This species stands out as an important oilseed with great potential of oil production with high physicochemical biodiesel quality (Dranski et al., 2017).

J. curcas species is a perennial plant, monoecious, belongs to Euphorbiaceae family that it has around 317 genus and eight thousand species (Silva et al., 2017). The plant is from Mexico, a country that it has a great genetic diversity found naturally (Manchillas et al., 2015). Besides raw material for biodiesel production, is used in biopesticides production, cosmetics and medicines formulation though latex that has antimicrobial, anticancer and anti-inflammatory function (Matos et al., 2018; Almeida et al., 2019).

Despite the high economic potential, *J. curcas* plants arouses little interest of farmers and has not attracted researchers to develop better genotypes and new managements practices. In respect to rusticity to a variety adaptation to edaphoclimatic conditions, many cultivated areas in cerrado has been decimated by plagues and diseases, specially stem-borer and broad mite control have not been elucidated yet (Rossato et al., 2017).

Stem borer is due to *Cophes notaticeps* bettle, Curculionidae family. Females penetrates the stem and lay eggs. After hatch, the eggs feeds with internal tissues, interrupt the vessels, that transport sap, and the plant dies. There is no chemical registrated to stem borer in *J. curcas*, and the control occurred with the extermination of the larva after the elimination of attacked plants.

Broad mite (*Polyphagotarsonemus latus*) is a polyphagous species that cause significant damages in young leaves in more than 60 families of plants. The eggs are laid in abaxial side of young leaves and, this mite, in particular, does not weave web. In *J. curcas*, this mite has life cycle around 5 days, from egg to adult. The attacked plants shows shriveled leaves with stagnant growth and, eventually, leaf abscission. The small size, short life cycle and infestation site turn into difficult broad mite control (Evaristo et al., 2013).

The development of management practices to control *Cophes notaticeps* and *Polyphagotarsonemus latus* like using silicon (Si) can represent economically viable owing to low cost and environmentally safe for not harm environment. In the last decades, there was an agreement between researchers in respect to functional role of silicon in plant nutrition and growth (Epstein, 1999; Carvalho Junior et al., 2014; Bukhari et al., 2015).

The usage of Si shows as a viable alternative and beneficial to plants under biotic and abiotic stress conditions, has been considerate as an anti-stress element to cultivated crops as regard to plague and disease resistance; tolerance to heavy metals toxicity; tolerance to drought and saline stresses and specially yield increments (Nascimento et al., 2018).

Based on these studies, this study has the hypothesis that *J. curcas* plants, when exposed to Si, respond positively to *Cophes notaticeps* and *Polyphagotarsonemus latus*. Aiming to elucidate physiological and agronomical aspects about Si role in *J. curcas* plants metabolism for later establishment of recommendation of a new management practice, the present study aimed to evaluate the effects of Si in growth, yield and resistance of *J. curcas* plants to *Cophes notaticeps* and *Polyphagotarsonemus latus*.

Material and methods

Experimental design

The study was carried out in two consecutive years with *J. curcas* plants with three years old in 3x2 spacing at State University of Goiás experimental field, Ipameri Campus (Lat. 17⁰ 43' 19'' S, Long. 48⁰ 09' 35'' W, Alt. 773 m), Ipameir, Goiás. The region has tropical weather with humid summer and dry winter (Aw) according to Köppen climate classification, and mean temperature of 20 ºC (Alvares et al., 2013). The soil of experimental field is classified as Oxisol (Embrapa, 2013). Liming and fertilization were performed according to Table 1 analysis following the technical recommendations for the crop (Laviola and Dias, 2008; Matos et al., 2014). The experiment was set up in randomized block design with five silicon concentrations (0, 10, 20, 40 and 80 mM L^{-1} in 30 mL/plant), five replications and two plants per plot, 10 plants for each treatment.

Table 1. Summary of chemical soil analysis performed at September of each year.

Year:Depth	pH $CaCl_2$	O. M. (g dm^{-3})	P-Mehlich (mg dm^{-3})	Sortive Complex (cmol dm^{-3})						V%
				K	Ca	Mg	Al	H+Al	CEC	
Year1: 0-20 cm	5,3	38,8	12,9	0,21	4,0	1,7	0,0	3,5	9,4	62,8
Year1: 20-40 cm	4,9	31,0	6,7	0,17	3,8	1,1	0,0	3,7	8,8	57,8
Year2: 0-20 cm	5,8	30,2	14,5	0,24	3,9	1,3	0,0	3,5	8,9	60,9
Year2: 20-40 cm	5,3	29,8	9,3	0,19	3,3	1,1	0,0	5,2	9,8	46,9

O. M. = Organic matter; V% = Base Saturation; CEC = Cations exchange capacity.

Initially, the silicon solution was prepared with pH adjusted to 5.5 (with phosphoric acid) to obtain a slightly acid solution to maximize the absorption of Si according to Pereira et a. (2009). From the dilution of the solution, the treatments were executed. The pulverization occurred in two steps in each year, trying to reach the entirely canopy of the plant and provide Si to mesophyll cells according to Bukhari et al. (2015).

The pulverizations (Year 1 and Year 2) were executed in the last week of October when the plants had a great number of mature leaves and the second pulverization after 30 days from the first one. Sought greater consistency during each application, through the pulverization of solution in the leaf area of *J. curcas* plants, reaching entire canopy, for this, a metering valve attached to the backpack sprayer. From the 60th day after the last pulverization were performed the analysis of growth, physiological, biochemical, yield and injury symptoms of *Cophes notaticeps* and *Polyphagotarsonemus latus*.

In March 2018 was set up the greenhouse assay following completely randomized factorial design 5x2 with five Si concentrations: (0; 10; 20; 40 and 80 mM L^{-1} in 30 mL/plant/application in four pulverizations at 20; 30; 40 and 50 day after emergence), two treatments of water regime: daily irrigation with 50% of field capacity and daily irrigation with 100% of soil capacity, six replications and one plant per plot.

J. curcas seeds were sown in 8 liters plastic pots containing a mixture of six kilograms of soil, sand and manure, with 3:1:0.5 proportion, respectively. The chemical soil analysis exhibited the following values: pH (CaCl2) 5.4; 16 g dm^{-3} organic matter; 68 mg dm^{-3} P; 6.81 mmolc dm^{-3} K (Mehlich-1); 22 mmolc dm^{-3} (SMP Method) H + Al; 31 mmolc dm^{-3} Ca; 15 mmolc dm^{-3} Mg; 53 mmolc dm^{-3};Base Saturation; 75 mmolc dm^{-3} Cation Exchange Capacity and 71% Base Saturation.

Subsequently the analysis, it was decided not to fertilize, according to recommendations for the crop (Santos et al., 2018). The seedlings were irrigated daily with water volume corresponding to 100% of daily evapotranspiration, until 20 days after emergence. The crop coefficient (kc) for *J. curcas* was not established for Ipameri, Go, region it was used kc=1.00 following FAO 56 (Allen et al., 1998) for a group of crops in initial development stage.

The analysis in field assays were: number of branches, plant height, stem and canopy diameter, concentrations of chlorophyll and carotenoids in leaves, specific leaf area (SLA), stomatal density, yield, silicon leaf content, enzyme activity of peroxidase, polyphenol oxidase, chitinase and phenylalanine lyase and symptoms of injury provoked by *Cophes notaticeps* and *Polyphagotarsonemus*. In the greenhouse experiment were evaluated: plant height, stem diameter, number of leaves, root length, leaf area, water relative content, transpiration rate, leaf nitrogen content, silicon, carotenoids and chlorophyll, biomass and SLA.

Growth variables

Plant height was measured from the root-stem transition region at soil level (crown) to the tip of the stem using graded rule. The stem and canopy diameter were measured at the crown and west-east direction with a graded rule. The number of leaves was obtained by counting. The roots, stems and leaves were separated and dried in an oven at 72 ºC until constant dry weight and the weighed. With the dry mass data was calculated the biomass with the sum of all parts of the plant and the ratio of leaf, stem and root mass calculated dividing the specific part by biomass. The leaf area was measured with the LI-COR machine, LI-3100 model, expressed in cm^2.

Physiological variables

To determine the total chlorophylls and carotenoids concentrations, 0.6 mm diameter leaf discs were removed from completely opened leaves and placed in test tubes containing 3 mL of dimethyl sulfoxide (DMSO) saturated with calcium carbonate 50 g L^{-1}. Then extraction was carried out in a water bath at 65 °C for one hour. Aliquots were removed for spectrophotometric reading at 480, 649 and 665 nm. Then contents of chlorophyll a (Cl *a*), chlorophyll b (Cl *b*) and total carotenoids (Car) were determinate according to the equation proposed by Wellburn (1994).

Maximum quantum efficiency of photosystem II (F_v/F_m) was measured with fluorometer (Junior-Pam). After acclimation in dark for 30 minutes, the leaves were exposed to a low far-red light pulse (1-2 µmol m^{-2} s^{-1}), to stablish initial fluorescence (F_0). Then, a saturating light pulse, with 6000 µmol (photons) m^{-2} s^{-1} for 1 second, was used to estimate the maximum fluorescence (F_m).

One replica of adaxial and abaxial leaf surface was removed with a colorless nail polish of middle third of plants, previous dehydrated. The stomatal counting was performed using an optical brightfield microscope. Stomatal density was performed through stomatal counting in 1 mm^2 area, number of stomata/area (Borges et al., 2014).

To obtain SLA, foliar discs were retired from a known area (12 mm diameter) of completely expanded leaves that posteriorly were dried in an oven at 65ºC for 72 hours, to measure dry mass and, then, calculate the SLA divided by mass.

To obtain relative water content, five foliar discs of 1.2 cm diameter were retired from completely expanded leaves, weighted to measured fresh mass (FM) and saturated for 24 hours in petri dishes with distilled water and weighted again, determining turgid mass (TM), then, put it to dry at 70ºC for 72 hours, and, posteriorly, dry mass (DM), and calculated the relative water content with following equation: (FM - DM)/(TM - FM).

Plant daily total transpiration was measured by the difference of pot weights. Initially, each pot was covered by a plastic bag tied in the plant stem, just the shoot part (leaves and stem) out of the bag, then, the pot, with the plant, and the bag were weighted (mass 1) and 24 hours later weighted again (mass 2). Total transpiration was measured by the difference of mass 1 and mass 2.

Enzymatic variables

To enzymatic variables, the leaf discs were weighted, then frozen in dry ice and stored in minus 80ºC to further analysis. The frozen leaves were homogenized with 10 mL buffer phosphate 0.05 M (pH 7.0), containing 1 mg of polyvinylpyrrolidone-10. The substance were filtered, centrifuged at 4000 g for 20 minutes, under refrigeration, and the precipitate discarded. The supernatant was preserved in ice and used to determine the polyphenoloxidase and peroxidase. Polyphenoloxidase activity (EC 1.11.1.7) was measured at 30ºC, through the spectrophotometric method by the conversion to guaiacol to tetraguaiacol at 470 nm (Luso and Pascholati, 1999). To evaluate the chitinases activity (EC 3.2.1.14), it was used the method by Wirth and Wolf (1990), in which, occurs the release of soluble fragments of carboxymethyl chitin remazol brilliant violet. Phenylalanine ammonia-lyase activity was measured according to the method proposed by Silva et. al (2004), from the conversion of L-phenylalanine to cinnamic acid at 290 nm. The phenolic compounds were extracted from dry leaves, according to Swain and Hillis (1959).

Injury symptoms

Injury symptoms provoked by *Cophes notaticeps* and *Polyphagotarsonemus latus* were measured 60 days after the Si pulverization. To evaluate the injuries provoked by *Cophes notaticeps* and

Polyphagotarsonemus latus, it was used a visual damage scale proposed in this project to *Cophes notaticeps* and described by Evaristo et al. (2013) *to Polyphagotarsonemus latus* as described in Tables 2 and 3.

Table 2. Note scale to evaluate the injury of stem borer, *Cophes notaticeps*, in *J. curcas* plants.

Note	Injury
0	No injury, green stem, without damages.
1	Stem with hardly identifiable lesions, but with visible leak of brown sap.
2	Stem with easily identifiable lesions and visible leak of brown sap, stem with slight peeling close to the ground.
3	Stem with visible leak of brown sap, severe peeling. Presence of wood powder on the ground close to the stem. Senescent young leaves and leaned or toppled plants.

Source: Proposed by author.

Table 3. Note scale to evaluate the injury of broad mite, *Polyphagotarsonemus latus*, in *J. curcas* plants.

Note	Injury
0	No injury, green and expanded leaves, bright green.
1	Apical leaves with slight corrugation on the surface.
2	Apical leaves with corrugation and wilting.
3	Apical leaves well corrugated and wilted. Abaxial surface with many white points (immature broad mite).
4	Rough apical leaves, without bright, progressing to drop leaves and apical meristem death.

Source: Evaristo (2011).

Yield and nutrition variables

Yield was measured weighting the harvested fruits (harvest season was from December to April of each ear) with 13% of humidity. The estimation of Si and N content in expand leaves were performed at Plant Production Laboratory in UEG. Leaves samples were collected and set the difference of Organic-N and Nitric-N, as described by Cataldo et al. (1974, 1975). The sum of the fraction represents Total-N. To Si analysis, the material was submitted to silicon-molybdate method described by Kondörfer et al. (2004).

Statistical analysis

The data were submitted to regression analysis with coefficient of determination (R^2), determined by sum of square. Indval multivariate analysis, correlation network analysis using qgraph package, canonical variables using candisc package and multiple regression analysis using forward stepwise model (SOKAL and ROLF, 1995) were performed using softwares R 4.0.1 (R core team, 2020), RBIO (Bhering, 2017), SigmaPlot 10.0 (Systat software, 2006) and Statistica (Statsoft, 2007).

Results and discussion

The results demonstrates that the greenhouse experiment none variables adjusted to regression models, linear or quadratic, at 5% probability, in other words, 100% of measured variables did not show statistical difference related to variation in silicon concentrations.

The plants showed differences between years analyzed (field experiment) and also water deficit (greenhouse experiment) respectively, however, the differences are not correlated to silicon usage, thus, for not being the focus of the study, to deepening in the subject is impertinent, since the effects of silicon in mitigate biotic and abiotic stresses represented the assays at the field and greenhouse. It was common, during the field experiment, periods without rain (April to September) and under this circumstances it was not observed effects of silicon to mitigate water deficit. The benefits of silicon to attenuate biotic stresses in accumulating plants appears no to occur at the same magnitude in *J. curcas*. According to Dos Anjos et al. (2017), silicon exert few effects in *J. curcas* growth for being a non-accumulating species.

The field results showed in Figure 1 demonstrates that the yield and specific leaf area showed 42% and 12% decrease in plants under 80 mL Si when compared to control plants, respectively. The stem diameter decreased when plants under 80 mL Si are compared with control plants, whilst the Si concentration in 1st year showed slightly leaf variation, always less than 1% (Figure 1).

The lack of significant variations of leaf area and stomatal density indicate to the few effects of Si in *J. curcas* leaf morphology, however, the decrease of specific leaf area certainly is related with increments of leaf thickness. The lowest specific leaf area can be associated to a formation of silicon layer, typical of Si-accumulation plants (Wang et al., 2017), however, *J. curcas* plants, the existence of this layer is still not registered in literature, can own an insufficient thickness to promote significant changes in growth, but somehow has relation with yield decrease. According to Matos et al. (2019), plant with thicker leaves shows less light transmittance and greater dissolution of solar radiation in canopy interior. Thus, the formation of microclimate in canopy interior by the dissolution of radiation results in increases of decoupling factor and reduces the canopy photosynthesis, grain yield and vegetative growth, as occurred in stem diameter.

Chitinase enzyme activity was 21% inferior in control plants comparing to plants under 80 mM L^{-1} of Si, whilst phenylalanine lyase activity was 39% inferior than plants under 80 mM L^{-1} of Si comparing to control. According Van et al. (2006), chitinase genes overexpression in plants, has increased plant resistance to pathogens, since the enzyme catalysis the hydrolysis of chitin polymers, cell wall components and able to show antimicrobial activity.

In this study, the positive variations of chitinase activity and reduction of phenylalanine lyase can indicate protection of biotic and abiotic stress tolerance respectively, the variations were enough to a significant quantitative control of injuries provoked by *Cophes notaticeps* and *Polyphagotarsonemus latus*, as well as damages caused by water deficit and, thus, the results do not collaborates to the finds by Waewthongrak et al. (2015), pointing that silicon as a elicitor of stimulus of enzyme defense mechanism as chitinase, during the plant-pathogen interaction.

Multivariate analysis Indval aiming to identify the association of *Cophes notaticeps* and *Polyphagotarsonemus latus* injuries with silicon is show in Table 2 and makes clear, through the significance, that the levels of injuries of broad mite and stem borer did not have relation with silicon supply in *J. curcas* plants field-grown. Multivariate analysis Indval demonstrates the lack of any association between the injuries caused by *Cophes* *notaticeps* and *Polyphagotarsonemus latus* with silicon in *J. curcas* plants.

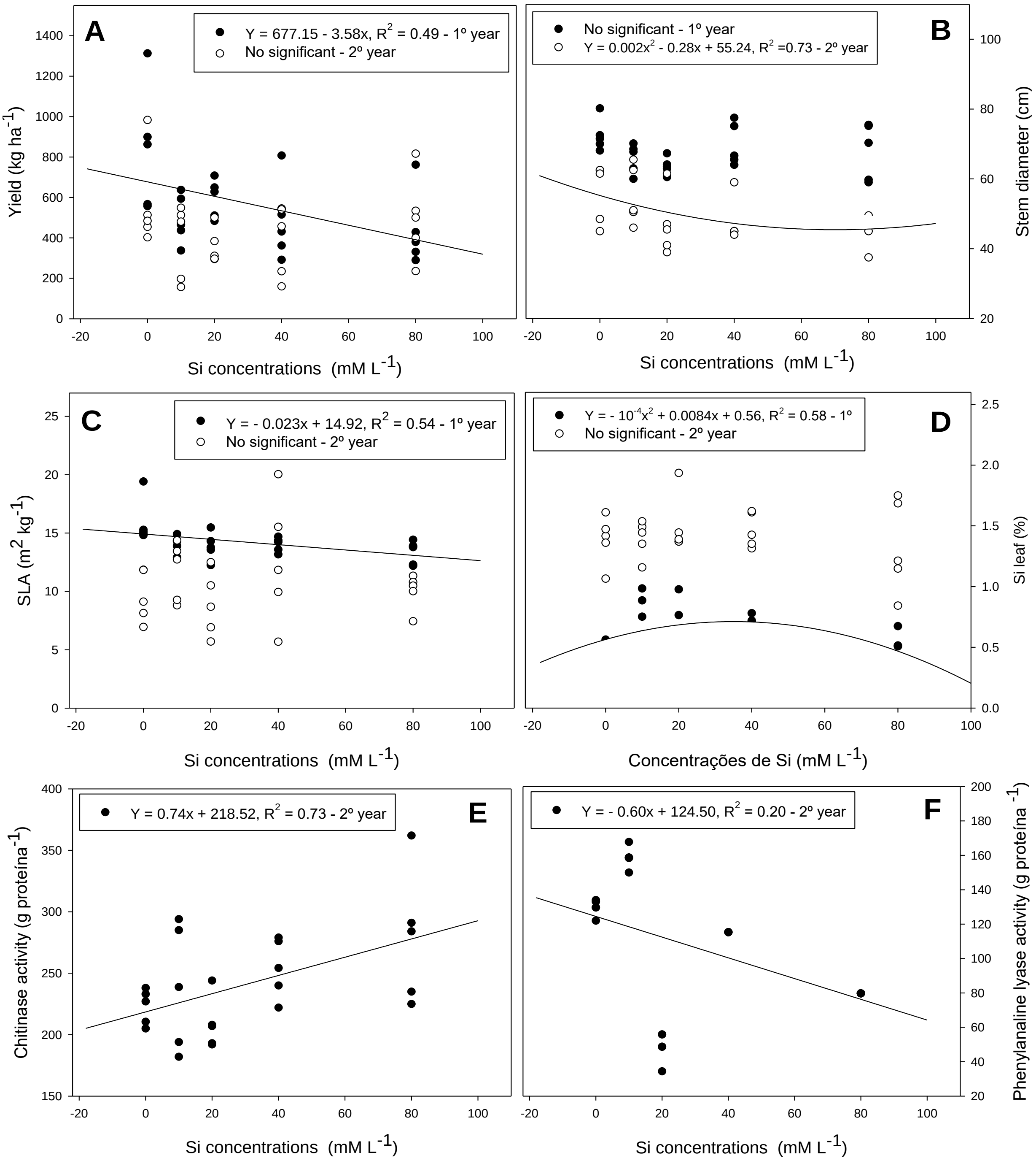

Figure 1. Regression equations for yield (A), stem diameter (B), specific leaf area (SLA – C), percentage of silicon in the leaf (Si – D) and chitinase (E) and phenylalanine lyase (F) activities in *J. curcas* plants in the field subjected to different concentrations of silicon.

Analysis of canonical variables showed in Figure 2 corroborates with the results of Indval. In the axis can 1 and can 2, is verified that the analysis of canonical variables represents 99.9% of data variation and shows the lack of significance between the treatments by F test at 5% of probability. Is possible to observe that the plants under lower Si concentrations (10 and 20 mM L^{-1}) are in opposite directions in axis can1 and the other treatments (0; 40 and 80 mM L^{-1}) in intermediary position, indicating the lack of any formation of homogeneous group and standard in group arrangement. According to Matos et al. (2019), the Si non-accumulating perennial plants shows lack or few morphologic variations under silicon fertilization; and the little biochemical variations were not enough to mitigate the damages.

Table 2. Multivariate Indval analysis to identify the association between injury severity caused by *Cophes notaticeps* and *Polyphagotarsonemus latus* separated into groups with the presence or absence of silicon in plants of *J. curcas* in the field sprayed with different concentrations of silicon.

Species	Silicon	Indval	p
Injury *P. latus* 1º year	Absence	0.78	NA
Injury *C. notaticeps* 1º year	Absence	0.73	NA
Injury *P. latus* 2º year	Absence	0.75	NA
Injury *C. notaticeps* 2º year	Absence	0.71	NA
Injury *P. latus* 1º year	Presence	0.48	NA
Injury *C. notaticeps* 1º year	Presence	0.67	NA
Injury *P. latus* 2º year	Presence	0.65	NA
Injury *C. notaticeps* 2º year	Presence	0.70	NA

NA = no significant at 5% probability.

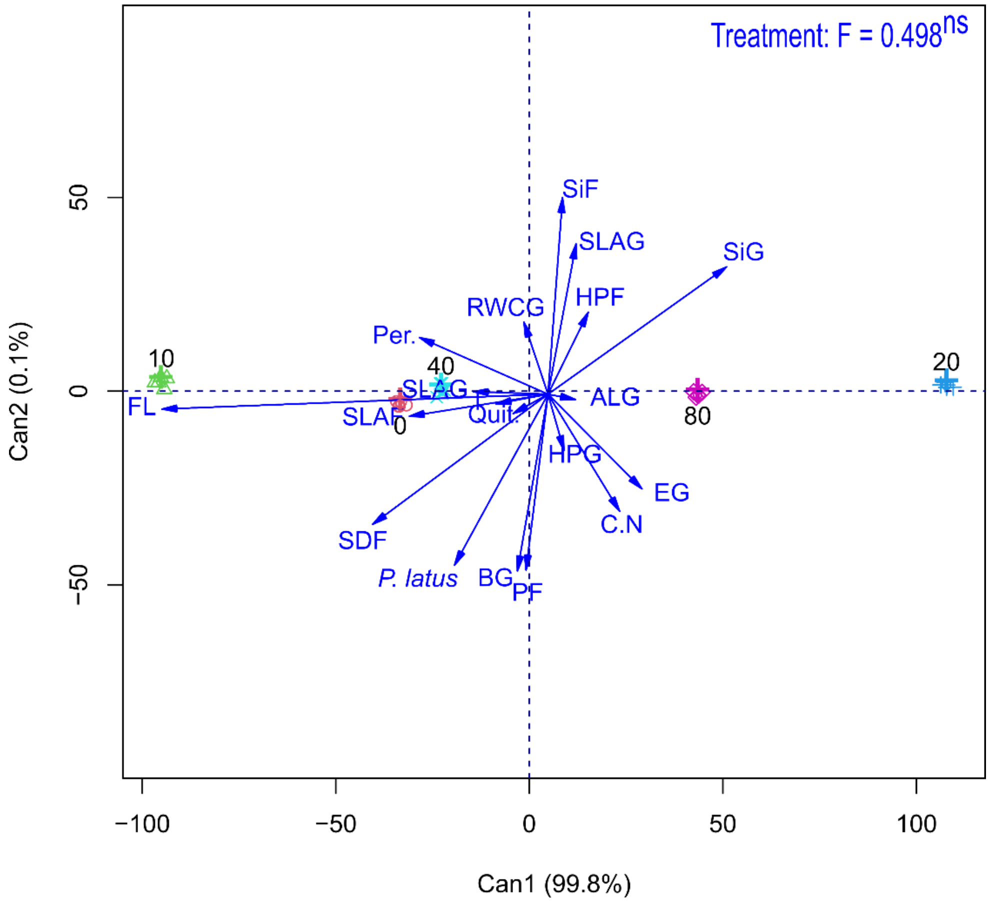

Figure 2. Analysis of canonical variables of plant characters of *J. curcas* submitted to different concentrations of silicon. The variables analyzed in the field are: plant height (HPF), stem diameter (SDF), productivity (PF), specific leaf area (SLAF), silicon

concentration in the leaf (SiF), injury caused by *Cophes notaticeps* (CN) and *Polyphagotarsonemus latus* (P. latus) and activities of the enzymes peroxidase (Per), chitinase (Quit.), Polyphenoloxidase (Pol.ox) and phenylalanine lyase (FL). The variables in the greenhouse are: Plant height (HPG), root length (RLG), leaf area (ALG), transpiration (EG), total biomass (BG), relative water content (RWCG), leaf concentrations of silicon (SiG) and specific leaf area (SLAG).

The results of multiple regression in Table 3 indicates that the injurie provoked by *Cophes notaticeps* is directly proportional to stem diameter. Is common to verify in the field that young *J. curcas* plants with thin stem diameter do not show *Cophes notaticeps* injuries, however, as the stem develop with the plant, reaching adult phase, is common the occurrence of *Cophes notaticeps* damages; this is due possibly by the needy of less fragile and more woody tissue for the activity of the pathogen and, by that, the young plants are more susceptible.

Table 3. Multiple regression analysis to assess the effect of the variables analyzed on the severity of the injury caused by *Cophes notaticeps* on plants of *J. curcas* under different concentrations of silicon.

Injury	R^2= 0.65		F (7,17) = 4.58		p<0.0000	
Cophes notaticeps	Beta	Std.Err. of Beta	B	Std.Err. of B	t (17)	p-level
Intercept			3.209	1.133	2.834	0.011
RMF	-0.471	0.173	-4.652	1.704	-2.730	0.014
DE	-0.413	0.151	-0.023	0.008	-2.728	0.014
Chl	-0.238	0.147	-0.501	0.310	-1.617	0.124
SD	0.352	0.156	0.024	0.011	2.261	0.037
RMR	0.301	0.153	12.984	6.597	1.968	0.066
Craiz	-0.218	0.160	-0.023	0.017	-1.362	0.191
Ntotal	-0.215	0.159	-0.014	0.011	-1.348	0.195

leaf mass ratio (LMR), stomatal density (SDY), total chlorophylls (Chl), stem diameter (SD), root mass ratio (RMR), root length (RL) and total nitrogen (TN).

Correlation network analysis (Figure 3) demonstrate strong positive correlation between growth variables: number of leaves (NLG), total biomass (BG), stem diameter (SDG) and Plant height (PHG). The positive correlation between stem diameter (SDG), root area (RAG) and root mass ratio (RMR) indicate strong correspondance between absorption of soil solution and translocation ability in the stem of *J. curcas* plants. The strong positive correlation between carotenoids (CarG) and chlorophylls (ChlG) refers to cooperative action of these pigments in absorption of ligh energy to photosynthesis, however, the stronge negative correlation between stem (SMRG) and leaf mass ratio (LMRG) indicate the competition for assimilates to leaf and stem development. Beyond that, is important to point that despite the investment in stem increase the hidraulic conductivity it can increase *Cophes notaticeps* injuries, by the woody tissue, propitious to pathogen action, however, was not observed strong correlations involving injuries severity provoked by *Cophes notaticeps* and *Polyphagotarsonemus latus*.

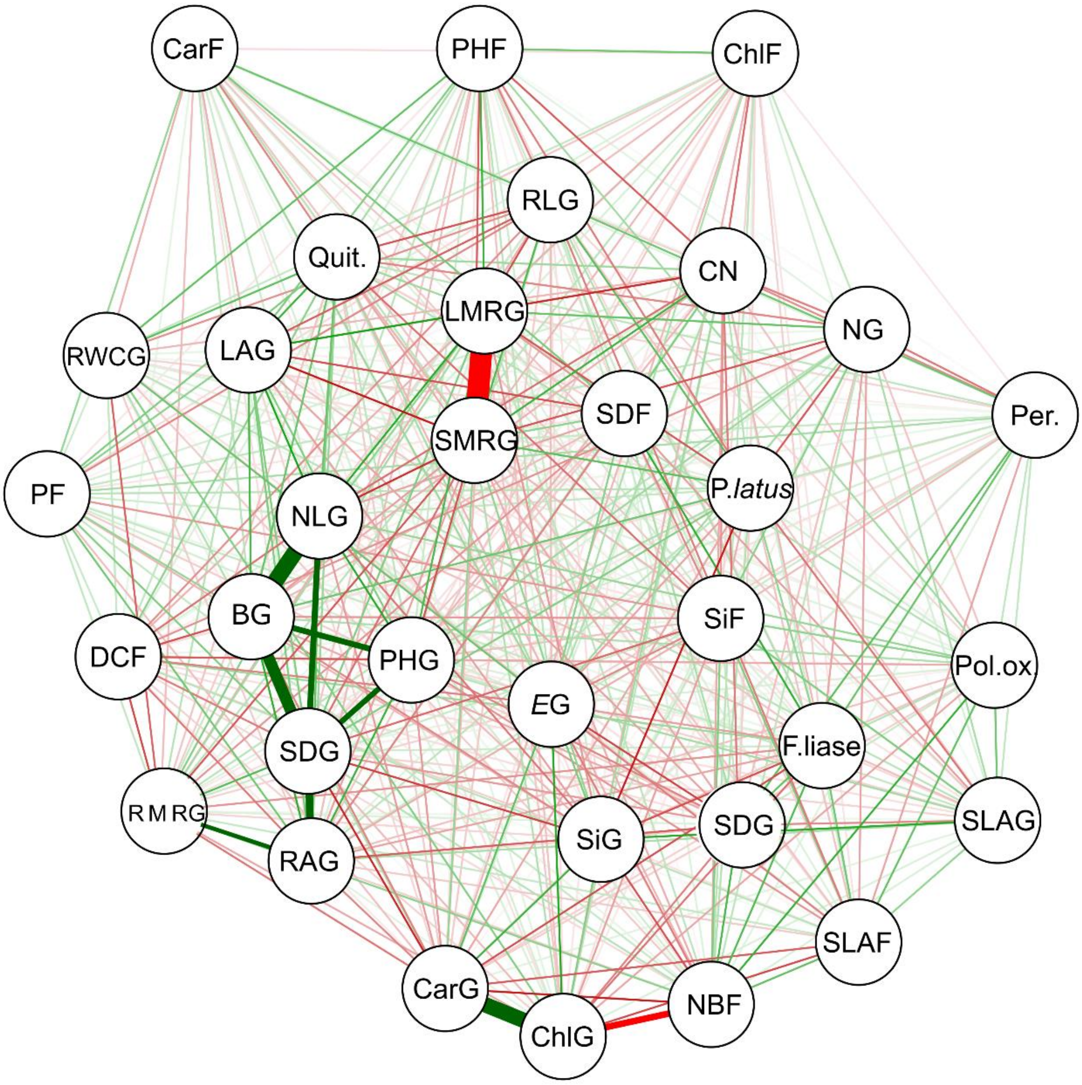

Figure 3. Phenotypic correlation network of plant characters of *J. curcas* submitted to different concentrations of silicon. The red and green lines represent negative and positive correlations, respectively. The width of the line is proportional to the strength of the correlation. The variables analyzed in the field are: Number of branches (NBF), plant height (PHF), stem diameter (SDF), canopy diameter (CDF), leaf concentrations of carotenoids (CarF) and total chlorophylls (ChlF), productivity (PF), specific leaf area (SLAF), silicon concentration in the leaf (SiF), stomatal density (SDF), injury caused by *Cophes notaticeps* (CN) and *Polyphagotarsonemus latus* (*P. latus*) and activities of the enzymes peroxidase (Per), chitinase (Quit.), polyphenoloxidase (Pol.ox) and phenylalanine lyase (F.liase). The variables in the greenhouse are: Plant height (PHG), stem diameter (SDG), number of leaves (NLG), root length (RLG), root area (RAG), leaf area (LAG), transpiration (EG), root (RMR), stem (SMRG) and leaf mass ratios (LMRG), total biomass (BG), relative water content (RWCG), leaf concentrations of silicon (SiG), nitrogen (NG), carotenoids (CarG) and chlorophylls (ChlG) and specific leaf area (SLAG).

The results indicate that silicon do not attenuate the damages provoked by *Cophes notaticeps* and *Polyphagotarsonemus latus* in *J. curcas* plants, moreover, the increase of concentration of this nutrient not promoted significant increases in vegetative growth and grain yield of *J. curcas*, also not change significantly the plant morphology.

Conclusions

The present study allows classifying the *J. curcas* plants as Si non-accumulator due to has less than 1% of content in leaves. The low accumulation of Si in leaves did not change vegetative growth significantly of *J. curcas* plants, however, the reduction of specific leaf area possibly by the formation of a thin silica layers reduced the yield by increasing the elimination of solar radiation.

Silicon did not mitigate the damage caused by *Cophes notaticeps* and *Polyphagotarsonemus latus* due to low capability of low accumulation of silicon, however, is possible to affirm that the severity of injuries caused by *Cophes notaticep* is proportional to stem diameter.

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