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ECOSYSTEMS

Effects of Iron on oxidative stress of *Cecropia hololeuca* and *Carica papaya* plants

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Abstract: Iron is essential to plant development. However, its excess can provoke an increase in reactive oxygen species and oxidative stress in plants. The objective of this work was to verify the effects of high concentrations of iron on the oxidative stress of seeds and young plants of *Cecropia hololeuca* and *Carica papaya*. The species were submitted to concentrations of 0.045, 4 and 8mM of iron in the form of ferrous sulfate and FeEDTA. The experiments of germination and initial growth took place in a growth chamber, with temperature of 25ºC and 12h photoperiod. We performed the lipid peroxidation test by extraction and quantification of malonaldehyde and hydrogen peroxide. The application of iron did not cause a significant elevation in the contents of malonaldehyde and hydrogen peroxide in the germination of *C. hololeuca* and *C. papaya*. In the young plants, the hydrogen peroxide did not change in any of the treatments. However, it was possible to observe an expressive increase in malonaldehyde concentration in both species when exposed to FeEDTA 4 to 8mM. The results indicate a sensibility of *C. hololeuca* and *C. papaya* to high iron levels, amplifying the oxidative stress process that can harm their growth and initial development.

Key words: *Carica papaya*, *Cecropia hololeuca*, Malonaldehyde, Peroxide.

INTRODUCTION

The growth of mining activity and processing of Iron ore (Fe), associated with the neglect of the waste from these processes, is considered one of the major factors responsible for increasing Fe levels in the environment (C.O. Rios 2017, unpublished data). This metal presents non-biodegradable characteristics and, when found in its soluble form, is considered one of the primary contaminants of waterways (Punshon et al. 2003, Bai et al. 2009). This situation can generate numerous adverse effects to the aquatic ecosystem because Fe can be readily usable by plants and is toxic when absorbed in excess. Fe toxicity is closely related to damage in several plant communities. The possible damage to the growth and fruiting of cultivated species and the establishment of riparian vegetation has been gaining increasing interest (Zhang et al. 2010, Barbosa et al. 2014).

Riparian forests stand out as one of the essential maintainers of environmental balance. They contribute to a lower rate of erosion and leaching, greater control of water flow to the soil, and maintenance of the quality of water that reaches water bodies (Castro et al. 2013). However, these forests can also retain a wide range of pollutants, especially Fe, which, due to its persistence in the medium, can accumulate in plant species and increase the environment's vulnerability (Torres et al. 2014). The species *Cecropia hololeuca* Miq. (Cecropiaceae), known as embaúba-prateada, is widely distributed in Brazilian territory and occurs mainly in riparian forests (Vicentini et al. 2008). Such fact can represent a risk to its development since it can absorb high concentrations of Fe and suffer from harmful effects to the growth and establishment (Sahrawat 2005, Saaltink et al. 2017). This situation was already observed for this species when exposure to elevated amounts of Fe, resulting in damage to the germination process, photosynthetic apparatus and severe growth retardation (Rodrigues Filho et al. 2020b).

Species *Carica papaya* L. (Caricaceae) is an important fruit species of high occurrence in the southeastern Brazilian region, especially in Espírito Santo. It represents one of the economic pillars of the state, with approximately 60 tons of fruit sold annually to the rest of the country and abroad (Ibge 2019). *C. papaya* crops are near regions with high levels of Fe-rich mining waste, so its productivity can be deeply affected by the elevation in the metal levels (C.O. Rios 2017, unpublished data). This crop, as well as other cultivated species, have a long history of harm when looking at contact with toxic amounts of Fe, as examined in plants of Lettuce, Soy, Coffee and Rice (Bataglia & Mascarenhas 1981, Krohling et al. 2016, Laurett et al. 2017, Rodrigues Filho et al. 2020a).

Fe is an essential micronutrient in plant development, acting at low concentrations. However, its excess is related to losses in germination and growth because it causes an increase in the content of reactive oxygen species (ROS) and the oxidative process (Becker & Asch 2005, Kobayashi & Nishizawa 2012). Among the main ROS originating by Fe contents' elevation, hydrogen peroxide (H_2O_2) stands out as one of the most stressful compounds due to its high production and oxidative capacity (Jucosky et al. 2013). Oxidative damage can occur in various parts of plant metabolism, but the occurrence of lipid peroxidation in the cell membrane, estimated based on the production of malonaldehyde (MDA), the final product of lipid peroxidation, is considered one of the most reliable variables that indicate the intensification of oxidative stress caused by high Fe levels and the beginning of the damage to the plant development (Jucosky et al. 2013, Pinto et al. 2016).

Thus, this work aimed to investigate the possible oxidative effects of high concentrations of Fe on seeds and young plants of *C. hololeuca* and *C. papaya*, that can compromise its development.

MATERIALS AND METHODS

Storage and the germination of the seeds

C. hololeuca and *C. papaya* seeds were stored in the Seeds and Forest Ecophysiology Laboratory of the Federal University of Espírito Santo in Vitória-ES in a cold chamber (5ºC) until the beginning of the experiment. For the analysis of possible oxidative effects on germination, seeds of both species were previously disinfected with 2% sodium hypochlorite for 2 minutes and placed in Petri plates lined with two sheets of filter paper and moistened with Fe solutions. It was used concentrations of 0.045 (control), 4mM and 8mM applied as ferrous sulfate and FeEDTA. We set up the experiment in a B.O.D. germination chamber under a constant temperature of 25 ºC and photoperiod 12h/12h for ten days (Ferreira & Borguetti 2005).

Production of the young plants

Seeds of both species were sown in 0.5L polyethylene pots with unfertilized substrate and washed sand in a 1:1 ratio to verify the oxidative stress on young plants. We set up ten pots with one plant each, with ten experimental units per treatment. Twenty days after germination, we subjected seedlings to the respective treatments using concentrations of 0.045 (control), 4mM and

8mM applied as ferrous sulfate and FeEDTA via soil. The cultivation took place in a growth room at 25º C, photoperiod 12h/12h, for fifty days. We kept all plants in Hoagland solution at half ionic strength and pH 5.0 (Hoagland & Arnon 1950).

The oxidative test through the quantification of H_2O_2 and MDA

It was verified the oxidation degree and cell damage through H_2O_2 and MDA contents for the seeds and young plants (Cakmak & Horst 1991). At the end of each experiment, we macerated 300 mg of seeds and young plant tissue samples using liquid nitrogen in 2.0 mL of 0.1% (w/v) trichloroacetic acid (TCA). The homogenate was centrifuged at 12,000 xg, 4º C for 15 min, collecting the supernatant. 1mL aliquots of the supernatant were used added to 1mL of 0.5% (w/v) thiobarbituric acid (TBA) solution prepared in 20% (w/v) TCA for MDA content. We incubated samples at 90 ºC for 35 minutes and then rapidly cooled them on ice. We took the readings at 532 nm and 600 nm. The MDA content was calculated from the extinction coefficient of 155 mM cm^{-1} applying the formula: MDA content (ηM) = $[({}_{A}532-{}_{A}600)/1.56]$ x 105 (Buege & Aust 1978). We based H_2O_2 content on the method of Alexieva et al. (2001). The reaction medium consisted of 0.5 mL of the supernatant added to 0.5 mL of 100 mM potassium phosphate buffer (pH 7.0) and 2 mL of 1 M potassium iodide (KI). We carried out the reaction in the dark for one hour, and the absorbance reading was at 390 nm. We calculated the H_2O_2 concentration using a standard curve.

Statistical analyses

We performed both experiments in an entirely randomized design. Results data were submitted to variance analysis (ANOVA) and later to Tukey's test at a 5% significance level. We did all statistical analyses using the program Sisvar version 5.6 (Ferreira 2011).

RESULTS AND DISCUSSION

Fe stress on the germination

The results showed that exposure to the two Fe sources at concentrations of 4 and 8 mM did not cause an increase in MDA and H_2O_2 levels in the germination of *C. hololeuca* and *C. papaya* seeds (Figure 1).

High concentrations of heavy metals can profoundly affect seed germination, as already demonstrated in several works that verified the interaction of these compounds and the germination process (Akinci & Akinci 2010, Nasr 2013, Wan et al. 2013, Prodanovic et al. 2016). Other authors have also found deleterious effects when using high concentrations of Fe in wheat, bean, and Vigna genus species (El Rasafi et al. 2016, Verma & Pandey 2017). More specifically, in the germination of *C. hololeuca* and *C. papaya*, it was possible to observe a significant drop in the germination percentage of these two species when exposed to Fe (Rodrigues Filho et al. 2020a, b).

The multiple adverse effects caused by Fe can be attributed to biochemical disorders and decreased uptake of water and various ions in the soaking phase (Kobayashi & Nishizawa 2012). Another mechanism by which Fe can generate toxicity is by elevating H_2O_2 and other ROS levels (Becker & Asch 2005). In excess, these oxidizing compounds will accumulate in plant tissues and cause increased membrane lipid peroxidation and MDA contents (Siddiqui et al. 2011, Gall & Rajakaruna 2013, Seneviratne et al. 2019).

However, we did not verify this in the germination phase of *C. hololeuca* and *C. papaya* seeds since the concentrations of MDA and H_2O_2 did not show a significant difference between treatments, which seems not to indicate the

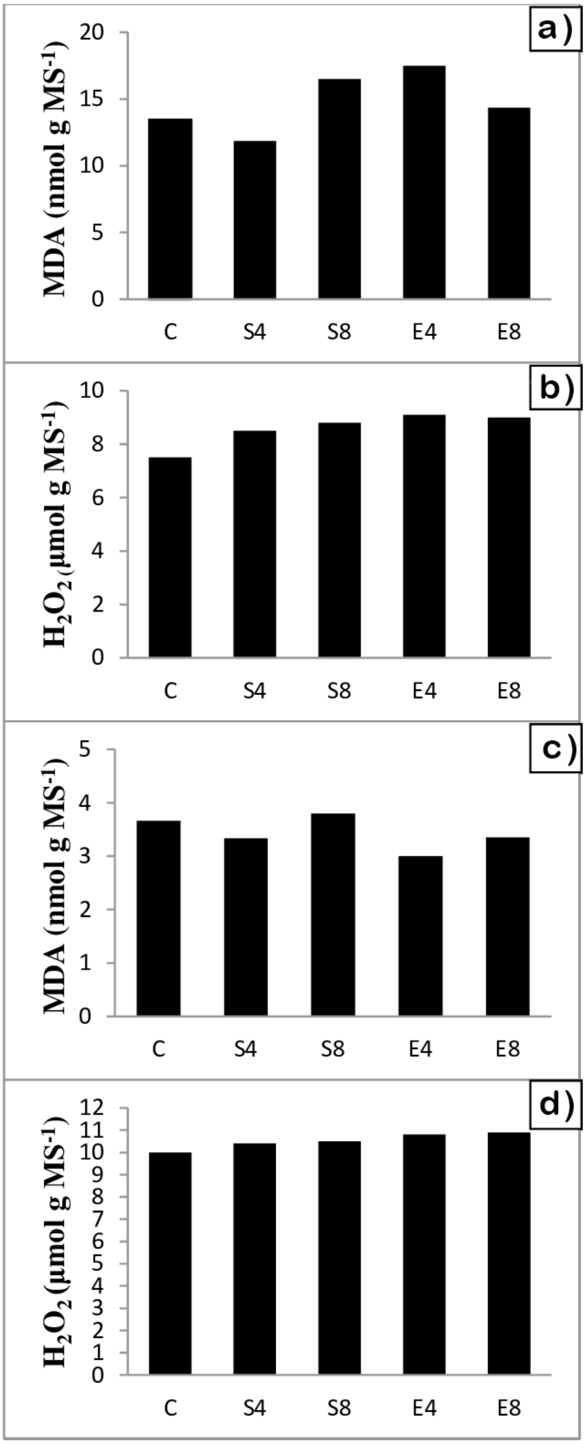

Figure 1. **MDA and H_2O_2 contents in germination of *C. hololeuca* a) and b) and *C. papaya* c) and d) seeds submitted to high Fe contents. (Tukey test, $p<0.05$). C: Control; S4: Ferrous sulfate 4mM; S8: Ferrous sulfate 8mM; E4: FeEDTA 4mM; E8: FeEDTA 8mM.**

presence of oxidative stress in the germination of both species. This can be explained by the nature of the integumentary layer, which can act as a physical block to metal contamination by limiting its absorption. Another strategy is seen through the increase of the antioxidant activity of the plant, reducing the levels of peroxidation and consequently the MDA contents, a fact already confirmed in some species exposed to high concentrations of Copper, Cadmium, and Fe (E.G. Pereira 2006, unpublished data, Banu Doğanlar 2013). Other protection systems can compartmentalize Fe in the cell vacuole by complexation to peptides and binding proteins, which prevents its activity (Souza et al. 2011, Fryzova et al. 2017).

Fe stress on young plants

Despite not promoting oxidative stress during the germination phase, high doses of Fe caused a significant increase in the MDA content in both species when exposed to FeEDTA in the initial growth and compared to the control (Figure 2). The concentration of this metabolite reached, respectively, a 30% and 140% increase in *C. papaya* and *C. hololeuca* plants when using the 8mM EDTA treatment. There was no difference in H_2O_2 content at this stage.

It was verified the oxidative effects of Fe under young plants of *C. hololeuca* and *C. papaya* for both concentrations of FeEDTA used. In the chelated version, Fe presents high absorptive capacity, triggering more significant accumulation in root tissue, the primary organ of absorption, and the first part of coming into contact with the metal, as well as in the stem and leaves of plants (Zhao et al. 2010, Onaga et al. 2016). The absorbed Fe entailed higher ROS production in young plants, which caused the peroxidation of membrane lipids, a fact proven by the significant increase in MDA contents of plants treated with 4 and 8mM FeEDTA. The increase

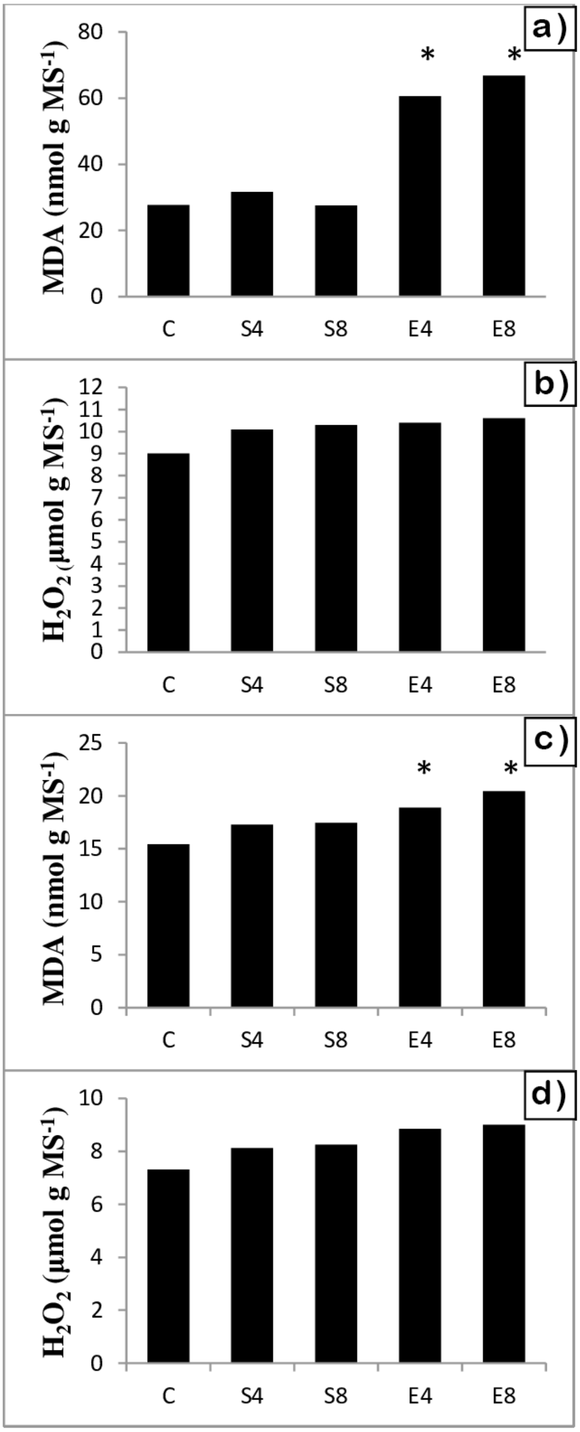

Figure 2. **MDA and H_2O_2 contents in young plants of *C. hololeuca* a) and b) and *C. papaya* c) and d) submitted to high Fe contents. The asterisk indicates significant difference compared to control (Tukey's test, $p<0.05$). C: Control; S4: Ferrous sulfate 4mM; S8: Ferrous sulfate 8mM; E4: FeEDTA 4mM; E8: FeEDTA 8mM.**

in the lipid peroxidation process associated with Fe is well known, entails severe effects on growth, and has been demonstrated in different forest and cultivated species (Sinhá et al. 1997, Kuki et al. 2008, Stein et al. 2008, Jucosky et al. 2013). The cell membrane is considered the first and primary site of the attack by ROS generated by exposure to high Fe contents. This attack, in turn, triggers the oxidation of lipids, which stimulates the increment of malonic aldehyde (MDA) content, a byproduct of the breakdown of membrane fatty acids and a probative factor of the presence of excess free radicals (Wu et al. 1998, Pinto et al. 2016).

However, initially, we cannot attribute the increased lipid peroxidation observed in this study to elevated H_2O_2 production. H_2O_2 is considered one of the primary and most common oxidizing agents produced by plants when exposed to high Fe concentrations, with the ability to easily cross membranes and degrade lipids and enzymes through the oxidation of their thiol groups (Gadjev et al. 2008, Karuppanapandian et al. 2011, Jucosky et al. 2013). We did not observe elevation in the content of this metabolite in *C. hololeuca* and *C. papaya* species when subjected to the two Fe sources at concentrations of 4 and 8mM. Similar results were found for *Oryza sativa* L. plants exposed to concentrations of up to 10mM of Fe, with an elevation of MDA without alteration in the H_2O_2 content (Fang et al. 2001). This fact may be justified by the antioxidant defense mechanisms present in plants, capable of neutralizing the toxicity of the various ROS produced, especially H_2O_2. Catalase and Peroxidases (POX) act effectively in the detoxification process, converting H_2O_2 to H_2O and molecular oxygen. This reaction prevents the elevation in the concentration of H_2O_2 and consequently the oxidative damage caused by this compound, a fact already verified in studies that evaluated the antioxidant capacity against high Fe contents (Jucosky et al. 2013). Moreover, when Rodrigues Filho et al. (2020a, b) worked with the species *C. hololeuca* and *C. papaya* subjected to Fe stress at concentrations of 8mM, they found an increase in POX enzyme activity when plants were exposed to FeEDTA, indicating a pathway of control of H_2O_2 levels and mitigation for this stress.

Also, the increase in MDA levels and lipid peroxidation in plants of both species exposed to FeEDTA seems to indicate other oxidizing compounds acting on these plants. Fe at high concentrations can also intensify the production of other ROS, such as the singlet oxygen ($^1O_2$) and the hydroxyl radical (HO^-). Recent studies have shown that $^1O_2$ can diffuse through all parts of the plant, and its action can primarily cause lipid peroxidation (Triantaphylidès & Havaux 2009, Barbosa et al. 2014). The hydroxyl radical (HO^-) can be formed directly by the action of Fe, or through the Fenton reaction, in which the H_2O_2 accumulated in tissues reacts with Fe giving rise to new HO^- molecules (Nikolic & Pavlovic 2018), a fact that can also explain the stability of H_2O_2 contents in plants. HO^-, in turn, is considered one of the most oxidizing ROS. Its excess causes changes in proteins through the oxidation of sulfhydryl groups, in nitrogenous bases, and damage to carbohydrate and fatty acid molecules, that can finally lead to lipid peroxidation (Barbosa et al. 2014, Pinto et al. 2016).

CONCLUSIONS

Seeds of *C. hololeuca* and *C. papaya* show no evidence of oxidative stress when exposed to 4 and 8mM concentrations of Fe during the germination period. However, in its EDTA form, Fe can generate oxidative damage in young plants of both species, promoting lipid peroxidation and consequently damage to metabolism and growth. Among the compounds responsible for this process, we discarded H_2O_2 and possibly the singlet oxygen and the hydroxyl radical stand out. Thus, high concentrations of Fe in the environment may be a limiting factor for riparian and cultivated species establishment.

REFERENCES

AKINCI IE & AKINCI S. 2010. Effect of chromium toxicity on germination and early seedling growth in melon (*Cucumis melo* L.). Afr J Biotechnol 9: 4589-4594.

ALEXIEVA V, SERGIEV I, MAPELLI S & KARANOV E. 2001. The effect of drought and ultraviolet radiation on growth and stress markers in pea and wheat. Plant Cell Environ 24: 1337-1344.

BAI J, CUI B, XU X, DING Q & GAO H. 2009. Heavy metal contamination in riverine soils upstream and downstream of a hydroelectric dam on the Lancang River, China. Environ Eng Sci 26: 941-946.

BANU DOĞANLAR Z. 2013. Metal accumulation and physiological responses induced by copper and cadmium in Lemna gibba, L. minor and Spirodela polyrhiza. Chem Speciat Bioavailab 25: 79-88.

BARBOSA MR, MEDEIROS MAS, WILLADINO L, ULISSES C & RANGEL CAMARA T. 2014. Geração e desintoxicação enzimática de espécies reativas de oxigênio em plantas. Ciênc Rural 44: 453-460.

BATAGLIA OC & MASCARENHAS HAA. 1981. Toxicidade de ferro em soja. Bragantia 40: 199-203.

BECKER M & ASCH F. 2005. Iron toxicity in rice-conditions and management concepts. J Plant Nutr Soil Sci 168: 558-573.

BUEGE JA & AUST SD. 1978. Microsomal lipid peroxidation. Methods Enzymol 52: 302-310.

CAKMAK I & HORST WJ. 1991. Effect of aluminum on lipid peroxidation, superoxide dismutase, catalase and peroxidase activities in root tips of soybean (Glicine max). Physiol Plant 83: 463-468.

CASTRO MN, CASTRO RM & DE SOUZA C. 2013. A importância da mata ciliar no contexto da conservação do solo. Renefara 4: 230-241.

EL RASAFI T, NOURI M, BOUDA S & HADDIOUI A. 2016. The effect of Cd, Zn and Fe on seed germination and early seedling growth of wheat and bean. Ekol Bratisl 35: 213-223.

FANG WC, WANG JW, LIN CC & KAO CH. 2001. Iron induction of lipid peroxidation and effects on antioxidative enzyme activities in rice leaves. Plant Growth Regul 35: 75-80.

FERREIRA AG & BORGUETTI F. 2005. Germinação: do básico ao aplicado. 1st ed, Porto Alegre, Artmed, 324 p.

FERREIRA DF. 2011. Sisvar: a computer statistical analysis system. Ciênc Agrotec 35: 1039-1042.

FRYZOVA R, POHANKA M, MARTINKOVA P, CIHLAROVA H, BRTNICKY M, HLADKY J & KYNICKY J. 2017. Oxidative stress and heavy metals in plants. In: De Voogt P (Ed), Reviews of Environmental Contamination and Toxicology. Reviews of Environmental Contamination and Toxicology (Continuation of Residue Reviews), Vol. 245, Amsterdam, Springer, Cham, NL, p. 129-156.

GADJEV I, STONE JM & GECHEV TS. 2008. Programmed cell death in plants: new insights into redox regulation and the role of hydrogen peroxide. Int Rev Cell Mol Biol 270: 87-144.

GALL JE & RAJAKARUNA N. 2013. The physiology, functional, genomics and applied ecology of heavy metal-tolerant Brassicaceae. In: Lang M (Ed), Brassicaceae: Characterization, functional genomics and health benefits. New York, Nova Biomedical, New York, USA, p. 121-148.

HOAGLAND DR & ARNON DI. 1950. The water-culture method for growing plants without soil. Calif Agric Experiment Station 347: 1-32.

IBGE – INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA. 2019. Produção Agrícola Municipal 2018. <https://cidades.ibge.gov.br/brasil/es/linhares/pesquisa/15/11863?indicador=11986&ano=2018&localida de1=0&tipo=ranking>. Accessed on December 28, 2020.

JUCOSKY GO, CAMBRAIA J, RIBEIRO C, OLIVEIRA JA, PAULA SO & OLIVA MA. 2013. Impact of iron toxicity on oxidative metabolism in young Eugenia uniflora L. plants. Acta Physiol Plant 35: 1645-1657.

KARUPPANAPANDIAN T, JUN-CHEOL M, CHANGSOO K, KUMARIAH M & WOOK K. 2011. Reactive oxygen species in plants: their generation, signal transduction, and scavenging mechanisms. Aust J Crop Sci 5: 709-725.

KOBAYASHI T & NISHIZAWA NK. 2012. Iron uptake, translocation, and regulation in higher plants. Annu Rev Plant Biol 63: 131-152.

KROHLING CA, EUTRÓPIO FJ, FIGUEIRA FF, CAMPOSTRINI E, DOBBSS LB & RAMOS AC. 2016. Níveis tóxicos de ferro em lavouras de café conilon (Coffea canéfora L.) em solos de tabuleiros costeiros. Coffee Sci 11: 255-266.

KUKI KN, OLIVA MA, PEREIRA EG, COSTA AC & CAMBRAIA J. 2008. Effects of simulated deposition of acid mist and iron ore particulate matter on photosynthesis and the generation of oxidative stress in *Schinus terebinthifolius* Radii and *Sophora tomentosa* L. Sci Total Environ 403: 207-214.

LAURETT L, FERNANDES AA, SCHMILDT ER, ALMEIDA CP & PINTO MLPB. 2017. Desempenho da alface e da rúcula em diferentes concentrações de ferro na solução nutritiva. Amaz J of Agric and Environ Sci 60: 45-52.

NASR N. 2013. Germination and seedling growth of maize (*Zea mays* L.) seeds in toxicity of aluminum and nickel. Merit Res J of Environ Sci and Tox 1: 110-113.

NIKOLIC M & PAVLOVIC J. 2018. Plant responses to iron deficiency and toxicity and iron use efficiency in plants. In: Hossain MA et al. (Eds), Plant micronutrient use efficiency, Cambridge, Academic Press, USA, p. 55-69.

ONAGA G, DRAMÉ KN & ISMAIL AM. 2016. Understanding the regulation of iron nutrition: can it contribute to improving iron toxicity tolerance in rice? Funct Plant Biol 43: 709-726.

PINTO SS, SOUZA AE, OLIVA MA & PEREIRA EG. 2016. Oxidative damage and photosynthetic impairment in tropical rice cultivars upon exposure to excess iron. Sci Agric 73: 217-226.

PRODANOVIC O, PRODANOVIC R, PRISTOV JB, MITROVIC A & RADOTIC K. 2016. Effect of cadmium stress on antioxidative enzymes during the germination of Serbian spruce [*Picea omorika* (Pan.) Purkyne˘]. Afr J Biotechnol 11: 11377-11385.

PUNSHON T, GAINES KF, BERTSCH PM & BURGER J. 2003. Bioavailability of uranium and nickel to vegetation in a contaminated riparian ecosystem. Environ Toxicol Chem 22: 1146-1154.

RODRIGUES FILHO J, CORTE VB, PERIN ITAL, DOS SANTOS CR & DA SILVA RW. 2020a. Effects of iron toxicity on germination and initial growth of Carica papaya L. Sci Plena 16: 1-12.

RODRIGUES FILHO J, CORTE VB, PERIN ITAL, DOS SANTOS CR & DA SILVA RW. 2020b. Iron Toxicity on Germination and Early Growth of Cecropia hololeuca Miq. Ensaios e Ciência C Biológicas Agrárias e da Saúde 24: 584-592.

SAALTINK RM, DEKKER SC, EPPINGA MB, GRIFFIOEN J & WASSEN MJ. 2017. Plant-specific effects of iron-toxicity in wetlands. Plant Soil 416: 83-96.

SAHRAWAT KL. 2005. Iron toxicity in wetland rice and the role of other nutrients. J Plant Nutr 27: 1471-1504.

SENEVIRATNE M, RAJAKARUNA N, RIZWAN M, MADAWALA HMSP, OK YS & VITHANAGE M. 2019. Heavy metal-induced oxidative stress on seed germination and seedling development: a critical review. Environ Geochem Health 41: 1813-1831.

SIDDIQUI MH, AL-WHAIBI MH & BASALAH MO. 2011. Interactive effect of calcium and gibberellin on nickel tolerance in relation to antioxidant systems in *Triticum aestivum* L. Protoplasma 248: 503-511.

SINHÁ S, GUPTA M & CHANDRA P. 1997. Oxidative stress induced by ironin Hydrilla verticillata Royle: response of antioxidants. Ecotox Environ Safe 38: 286-291.

SOUZA EP, DA SILVA IF & FERREIRA LE. 2011. Mecanismos de tolerância a estresses por metais pesados em plantas. R Bras Agrociência 17: 167-173.

STEIN RRJ, DUARTE GL, SPOHR MG, LOPES SIG & FETT JP. 2008. Distinct physiological responses subjected to iron toxicity under field conditions. Ann Appl Biol 154: 269-277.

TORRES IFA, DE ATAIDE COSTA T, ANDRADE MB, TEIXEIRA MDST, REIS LDPGR, DOS SANTOS RODRIGUES L & MELO MM. 2014. Elementos traço e agrotóxicos em amostras de água, sedimento e mata ciliar coletadas no entorno do ribeirão da mata (MG). Rev de Estudos Amb 15: 6-19.

TRIANTAPHYLIDÈS C & HAVAUX M. 2009. Singlet oxygen in plants: production, detoxification and signaling. Trends Plant Sci 14: 219-228.

VERMA L & PANDEY N. 2017. The Effect of Iron Toxicity on Seed Germination and Early Seedling Growth of Green Gram (*Vigna radiata* L. Wilczek). Int J Sci Res 6: 1427-1430.

VICENTINI E, REBOUÇAS MT, ARRUDA RA & RIBEIRO L. 2008. Aspectos demográficos de espécies de Cecropia em fragmento de mata ciliar da usina hidrelétrica Rio Bonito, Santa Maria de Jetibá–ES. Natureza Online 6: 66-73.

WAN M, WANG M, ZHOU F & YANG L. 2013. Effects of arsenic on seed germination of mung bean and black soybean. J Hubei University 3: 1-6.

WU P, HU B, LIAO CY, ZHU JM, WU YR, SENADHIRA D & PATERSON AH. 1998. Characterization of tissue tolerance to iron by molecular markers in different lines of rice. Plant Soil 203: 217-226.

ZHANG H, CUI B, XIAO R & ZHAO H. 2010. Heavy metals in water, soils and plants in riparian wetlands in the Pearl River Estuary, South China. Procedia Environ Sci 2: 1344-1354.

ZHAO K, LIU X, XU J & SELIM HM. 2010. Heavy metal contaminations in a soil–rice system: identification of spatial dependence in relation to soil properties of paddy fields. J Hazard Mater 181: 778-787.

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Author contributions

JRF, VBC and ITALP conceived and designed the study. JRF, RHW and CRS performed the analyses. JRF, VBC and JFNF interpreted the results. JRF, VBC, ITALP and JFNF participate in the writing of the manuscript. Moreover, JRF proceeded with the corrections and all of the other authors read and approved the final paper.