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Allelopathic influence of coffee roasting residue on cultivated species. Influência alelopática do resíduo da torrefação do café sobre espécies cultivadas.

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Abstract

The allelopathic effect of coffee roasting residue on the germination and development of seedlings of corn, soybean and cowpea was evaluated. The physiological quality of seeds and seedlings was determined by means of the germination test, first germination count, germination speed index, mean germination time, shoot and root length, shoot and root dry mass and the ratio of shoot dry mass and root dry mass. The use of coffee residue inhibited germination and reduced the germination speed and dry mass accumulation of the seedlings of the three evaluated species.
Keywords: *Glycine max* L. *Vigna unguiculata* (L.) Walp. *Zea mays* L. Germination. Vigor.

Resumo

Avaliou-se o efeito alelopático do resíduo de torrefação do café sobre a germinação e desenvolvimento de plântulas de milho, soja e feijão-caupi. A qualidade fisiológica das sementes e plântulas foi determinada por meio do teste de germinação, primeira contagem de germinação, índice de velocidade de germinação, tempo médio de germinação, comprimento da parte aérea e raiz, massa seca da parte aérea e raiz e a relação da massa seca da parte aérea e massa seca da raiz. A utilização do resíduo de café inibiu a germinação e reduziu a velocidade de germinação e acúmulo de massa seca das plântulas das três espécies avaliadas.

Palavras-chave: *Glycine max* L. *Vigna unguiculata* (L.) Walp. *Zea mays* L. Germinação. Vigor.

Introduction

Tons of residue generated in the coffee processing and roasting process are generated annually, and reuse has been one of the priorities of companies, whether for environmental, economic or social reasons (MOURA et al., 2018). From this perspective, there is a possibility of reducing the use of non-renewable sources of chemical fertilizers in agriculture, together with the need for proper disposal of organic waste in the environment (BENITO et al., 2005). However, the characterization of organic materials is necessary to prepare suitable substrates for the production of seedlings or use in the production of annual and perennial crops (LIMA et al., 2014; MOURA et al., 2018). This characterization is particularly important, as the inappropriate use of waste can generate risks to the environment such as contamination of the soil, water table, rivers and springs, in addition to causing problems for the establishment and production of crops (LIMA et al., 2014). In this perspective, the use of agricultural, urban and industrial residues in agriculture has been explored by different research groups aiming to reduce production costs associated with increased crop performance (KUMMER et al. 2016, SILVA et al., 2018, NEIVA JÚNIOR et al., 2019, ARAÚJO et al., 2020; ALAYU, LETA, 2020). However, studies reporting the use of coffee residues and its allelopathic effect are scarce and incipient (MOURA et al., 2018; LIMA et al., 2016).

Brazil is the world's largest producer of coffee and industrial processes along the production chain give rise to various residues (LIMA et al., 2014). Studies involving the use of these by-products such as bark, pulp and sludge indicate some level of inhibition on the plant, perhaps due to compounds that provide allelopathic effects such as caffeine, tannins, caffeic acid (LIMA et al., 2017). However, the studies are not concise and there is a report of a positive effect on the growth and production of plants, as the studies carried out for Moura et al. (2018) with different doses of the coffee roasting residue on the sunflower crop and this may be related to the dose or origin of the residue.

Allelopathy is a natural mechanism in which plant residues release compounds into the environment, which can benefit or harm organisms that are around them (LI et al., 2011). The action of released allelochemical compounds can act by attracting, repelling, nourishing or causing toxicity in the development of plant species (KONG et al., 2019).

The allelopathic inhibitory effects of several substances are directly associated with their concentration and studies indicate that young seedlings and seedlings are more sensitive to the deleterious effects of allelopathic substances (MAY et al., 2011; LIMA et al., 2016; MACÊDO et al., 2020), therefore, the use of seedlings allows for faster evaluation at the lowest cost.

Based on the hypothesis that residues from coffee processing have an allelopathic effect at low concentrations in seedlings of three cultivated species. Thus, this work aimed to evaluate the allelopathic effect of coffee residue on germination and seedling development of corn, soybean and cowpea crops.

Material and methods

The experiment was conducted at the Seed Analysis Laboratory of the Department of Fitotecnia, of the Center for Agricultural Sciences of the Federal University of Ceará, *Campus* do Pici, Fortaleza – CE, were selected for the study seeds maize (*Zea mays* L., variety cruzeta), soybean (*Glycine max L*., BRS 326) and cowpea (*Vigna unguiculata* (L.) Walp. cultivate setentão). The seeds were stored in a cold chamber at a temperature of 10 ºC and relative humidity of 50%.

The residue was obtained after the coffee processing process, where the bean that is roasted, ground and packaged is separated from the other parts that constitute (peel, pulp and parchment), these by-products corresponding to 50% are used as a source of energy to generate heat and thus roast the grain, at an average temperature of 270 °C.

Was used the ash generated after the pyrolysis process of the peel, pulp and parchment, whose chemical characteristics are: N: 12,9g kg^{-1}, M.O: 331,2 g kg^{-1}, P: 7,1 g kg^{-1}, P2O5: 16,3 g kg^{-1}, K: 83,3g kg^{-1}, K2O: 101,6 g kg $^{-1}$, Ca: 48,6 g kg_{-}^{1}, Mg: 28,7 mg kg^{-1}, Fe: 4.632,9 mg kg^{-1}, Cu: 216,9 mg kg^{-1}, Zn: 71,9 mg kg^{-1}, Mn: 219,5 mg kg^{-1}.

The experimental design used was completely randomized in a factorial scheme 3 x 5, being three cultures (maize, soybean and cowpea) and five levels of coffee residue (0, 2, 4, 6 e 8%) distributed in five repetitions of 50 seeds in the plot. The different concentrations of the residue were prepared by diluting in distilled water and homogenized for five minutes in Becker with the aid of a glass rod. After this process, the solution was sieved, thus eliminating the insoluble proportion. Then the solution was used to hydrate the germitest paper used in the research.

For the three cultivars studied, the germination test was performed, the first germination count, as recommended for each species, with the results expressed as an average percentage based on the number of normal seedlings (BRASIL, 2009).

The germination speed index was calculated by the sum of the number of seeds germinated each day, divided by the number of days elapsed between sowing and germination, according to Maguire's formula (1962) The average germination time calculated according to Labouriau, Valadares (1976).

After germination counting, 20 seedlings of each repetition were randomly selected. where the length of the aerial part and root was obtained with the aid of a millimeter ruler. After this process, the aerial part of the root was sectioned to determine the dry mass that was obtained after drying the material for 72 h in an oven with forced air circulation at a temperature of 65 ºC, the relation of shoot dry mass and root dry mass was also determined.

Data were subjected to normality analysis by the test of Shapiro Wilk and after the analysis of variance (ANAVA), when significant to the means of the three species were compared by the Tukey test the ($p \leq 0.05$) error probability and residual concentrations by means of polynomial regression using the software SISVAR (FERREIRA, 2011). Data were also subjected to principal component analysis (PC), and treatments were plotted in relation to the first two componentes (PC1 and PC2). Analyzes were performed using the software R v.4.0.1 (R DEVELOPMENT CORE team, 2020).

Results and discussion

Based on the summary of the analysis of variance, differences were observed between species for all traits ($p < 0.01$) except for the shoot length. The physiological quality of seeds and seedlings was affected by the level of coffee residue in all variables ($P < 0.01$) and interaction between species and residue level was not significant ($P > 0.05$) only for aerial part and root length (Table 1).

Table 1 - Summary of the analysis of variance for the physiological quality of seeds and seedlings of soybean, cowpea and corn, subjected to different levels of coffee residue.

VF	Ger	FGC	GSI	AGT	SL	RL	SDM	DRM	SDM/DRM
Spa (S)	122.82**	644.48**	314.26**	161.97**	1.45^{ns}	35.16**	1695.4**	357.82**	289.34**
Level (L)	11.83**	63.61**	127.52**	121.41**	392.20**	231.97**	8.28**	46.41**	32.15**
S x L	2.73**	12.91**	14.81**	11.15**	1.75^{ns}	1.79^{ns}	20.91**	11.37**	10.47**
Error	34.16	24.4	1.24	0.043	0.379	0.879	0.015	0.001	15.44
C.V. (%)	7.01	6.88	8.26	5.92	16.02	18.53	8.69	17.57	25.02

** e ns, significant the 1% and not significant by the F test of the analysis of variance. Ger. germination; FGC: first germination count; GSI: germination speed index; AGT: average germination time; SL: shoot length; RL: root length; SDM: shoot dry mass; DRM: dry root mass; SDM/DRM: relationship between shoot and root dry mass.

The shoot and root lengths were linearly reduced with increasing residue concentrations (Figure 1A and 1B). In the comparison between the species, soybean showed a reduction of 32 e 35% in root length compared to corn and cowpea, respectively (Figure 1C). The physiological role of caffeine, as well as other alkaloids in plant metabolism is not fully understood. Corroborating these results, the use of coffee extract in *Amaranthus viridis* L and *Cucumis sativus* L., showed a reduction in root length that was attributed to the allelopathic effect (MAY et al., 2011). Similar response with reduction in root length was also observed by Cunha et al. (2014), using 100% of coffee straw as substrate in the production of lettuce seedlings.

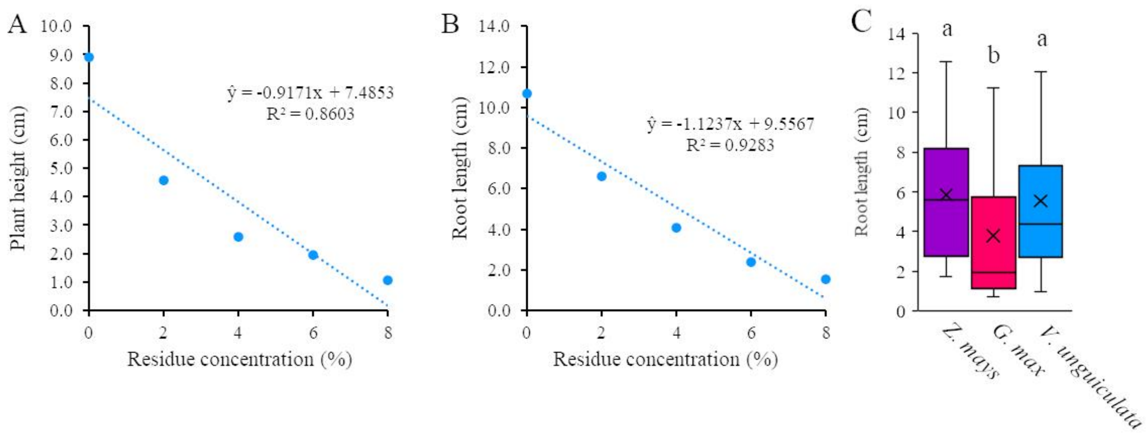

Figure 1 - Biometrics of soybean, cowpea and maize seedlings subjected to different levels of coffee residue. A: length of aerial part; B: root length as a function of coffee residue levels; C: root length as a function of species.

Analyzing the unfolding of the interaction, in the first germination count (FGC) was observed decreasing linear behavior for corn and cowpea, with corn being more sensitive with a reduction in 43% when compacted the highest concentration of residue (8%) in relation to control. Soybeans showed a quadratic behavior with maximum germination (80%) in the concentration of 2.2% of the residue, while the comparison between species showed less sensitivity in cowpea (Figure 2A-C). Germination also showed a similar response, however, the reduction was smaller in relation to FGC (Figure 2D-F). According Padilha, Coelho e Andrade (2020) the efficiency of seed reserve mobilization can be affected by the characteristics of the genotype and its initial physiological quality, being decisive in the choice of cultivars that present better physiological performance in the field.

Corroborating the results presented in this study May et al. (2011) using coffee husk extract (*Coffea arabica*) on cucumber germination and growth (*Cucumis sativus*) observed that the germination of cucumber seeds was significantly affected by the increase in the concentration of this extract. These authors found a reduction in the formation of normal seedlings and greater root sensitivity, observing necrosis and anomalies, such as thickening and bending.

Studies on allelopathic implications between species are very important, as they allow knowing the effects of intraspecific plant interactions, that can be noticed, through the germination and the germination speed index (GSI) (MOREIRA, 2018).

GSI presented a decreasing linear result for the three species. The cowpea showed a reduction of 49% of control in relation to higher concentration of coffee residue, while maize and soybeans presented 36 e 43% of reduction, respectively (Figure 2G-I). The average germination time (AGT) showed the opposite behavior, needing more time at 8% residue concentration, in fact, more intense in maize (Figure J-L).

Studies indicate that the inhibitory effect of coffee is not restricted to husk and seeds, restricted to husk and seeds, as aqueous extracts of plant tissue such as leaves, stems and roots, inhibited germination, and the growth of rice and lettuce rootlets; lettuce seedling growth was inhibited even at concentrations of 1% of the aqueous extracts, which contained caffeine among other allelopathic constituents (CHOU; WALLER, 1980). Also according to these authors, several components were identified in the extracts such as caffeine, theobromine, theofiline, paraxantine and chlorogenic, ferulic, coumaric and caffeic acids, with the exception of the last one, all exhibited an allelopathic effect, in a concentration of 0,01%.

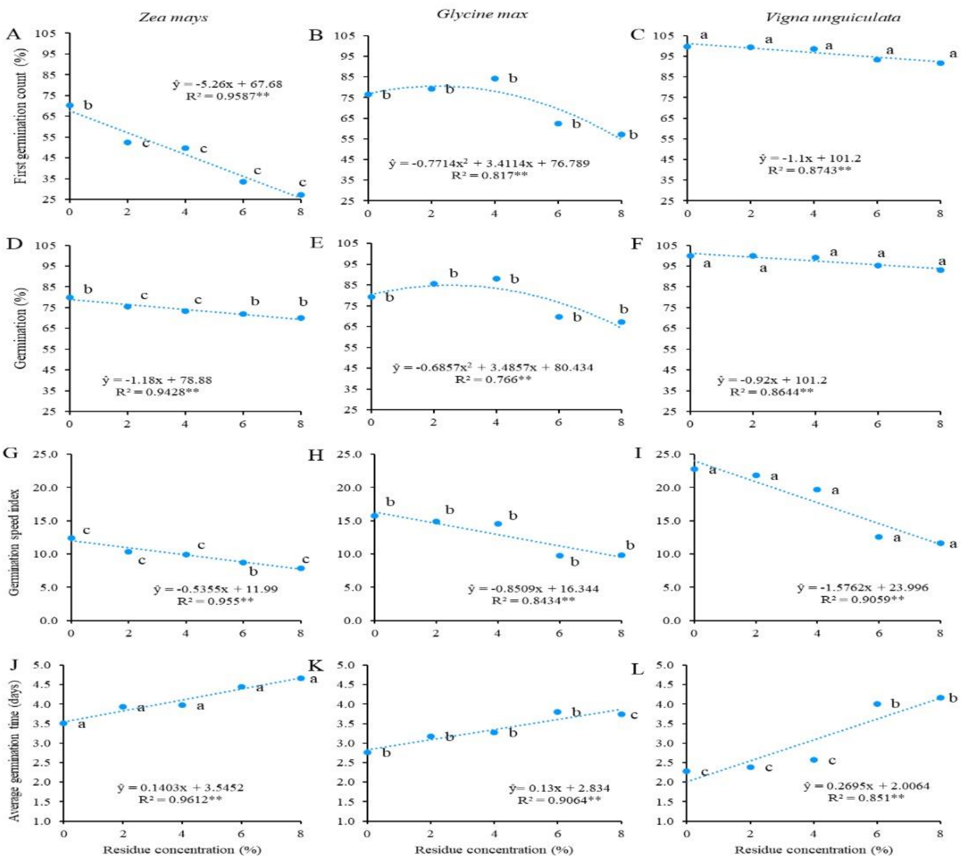

Figure 2 - Physiological quality of seeds from *Glycine max, Vigna unguiculata* e *Zea mays* subjected to different levels of coffee residue. A-C: first germination count (FGC), D-F: germination (GER), G-I: germination speed index (GSI), J-L: average germination time (AGT). ** indicates significance of the equation a 1% by the test F. Lowercase letters compare means between species at each dose.

The dry mass of the aerial part of the corn was linearly reduced as a function of the increase in the concentrations of the coffee residue, however, in the other species was observed opposite behavior, showing linear increasing behavior (Figure 2A-C), probably because they belong to the same botanical family, the strategies for tolerance to the deleterious effect of coffee residue are similar.

Regarding root dry mass with increasing concentration, it was observed that there was a reduction in all species studied when compared to the control (Figure 4D-F) and by analyzing the relationship between shoot dry mass and root dry mass, observed a similar behavior of soy and cowpea, where there is an increase as concentrations rise, This fact was not observed for maize, as the regression models were not significant. Corroborating, Oliveira et al. (2019) evaluating the production of papaya seedlings *(Carica papaya* L) using coffee straw-based substrate observed a reduction in SDM and DRM when used 60 and 75% coffee straw in the substrate formulation, being associated with the allelopathic effect of the large amount of coffee straw present in the substrates.

Even in very low concentrations of the coffee husk extract, Santos et al. (2002), observed that the root was highly sensitive to the allelopathic influence of this extract. According Oliveira et al. (2014) there is no pattern of germination, that is, different concentrations (higher or lower) often affect this parameter differently, and this goes according to the species tested. However, in that study it was observed that the highest concentrations negatively influenced the germination of the three tested cultures.

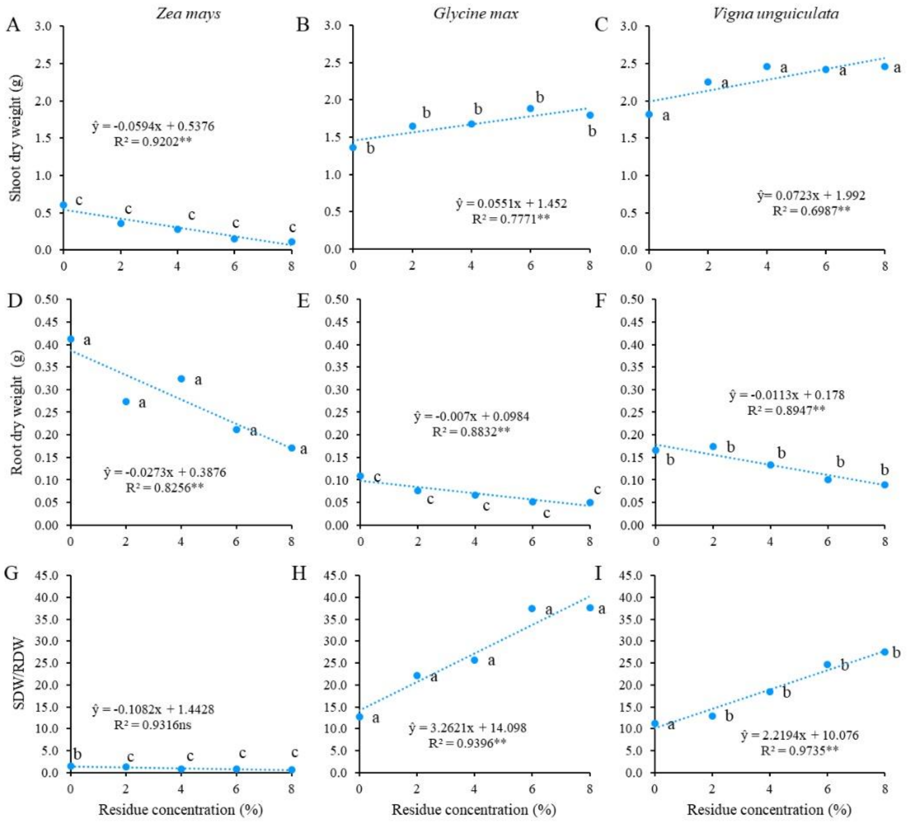

Figure 3 - Biometrics of soybean, cowpea and maize seedlings subjected to different levels of coffee residues. A-C: shoot dry mass (SDM); D-F: dry root mass (RDM) and G-I: relationship between shoot and root dry mass. ** and ns indicates significance of the equation in 1% and not significant by the test F, respectively. Lowercase letters compare means between species in each dose.

The results reported in this study demonstrate that the increase in residue from coffee roasting acts directly in inhibiting the accumulation of dry mass in the roots. Probably associating the highest concentration of allelochemicals (FERREIRA et al., 2020). And the fact that the roots are more sensitive, as they are in direct contact with the solution containing the inhibitor compounds.

The first two components contributed with 86.5% of the total variation of the data (Figure 4A). The factor loadings with the greatest contribution to the PC1 were GSI, FGC, GER, AGT, SDM, in the second component the relationship SDM/DRM, SDM, RL and SL were the characteristics with the greatest contribution (Figure 4B, C). Regarding correlations, high magnitude positives were observed between SL x RL ((r = 0.95); GER x GSI (r = 0.84); FGC x SDM (0.86). Already the AGT showed a strong negative correlation with most variables, with emphasis on FGC and GSI r = - 0.75 - 0.94, respectively (Figure 4D).

Was observed wide variability between treatments when subjected to different levels of coffee residue, being observed greater sensitivity in the corn maize, where all the residue levels formed the same group, and this group was mainly influenced by the AGT, while the control treatment (0% residue) formed an isolated group with influence of root length and dry mass. The cowpea, was considered the most tolerant species to the levels of coffee residue, as the control treatment comprises the same group of seeds that received 2 e 4% of the residue and these treatments are mainly influenced by the characteristics GIS, GER and PGC. Soybeans showed intermediate responses in relation to other species (Figure 4E). These results indicate that the cowpea has tolerance mechanisms to the allelopathic effect of the coffee residue, opening the perspective for future studies.

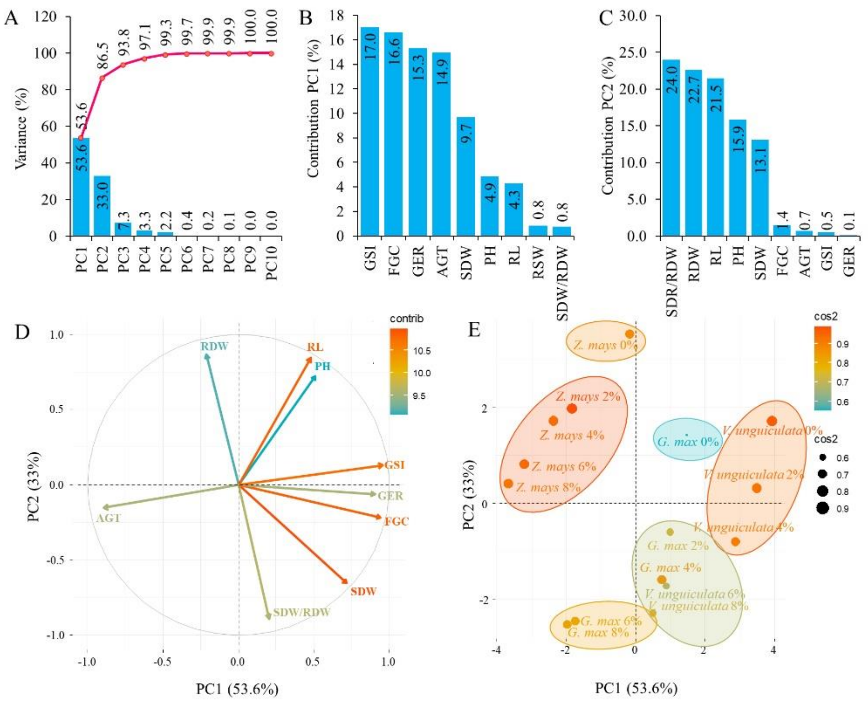

Figure 4 - Analysis of principal components for the physiological quality of seeds and biometrics of soybean, cowpea and maize seedlings subjected to different levels of coffee residue. A: contribution of each main component and accumulated contribution; B: contribution of eigenvalues to the first component; C: contribution of eigenvalues to the second component; D: circle correlation with contribution of characteristics, the arrows represent the direction of the feature and the color gradient represents the contribution of each feature to the components. From blue to red: low to high contributions. E: distribution of treatments according to the first two components, the color gradient indicates the contribution of the first two components to explain the variation of treatments which is also represented by the size of the circles that varies from 0.6 a 0.9.

Despite the evident inhibitory effect studies also obtained positive responses when using composted coffee grounds with higher production of aboveground biomass of *Lactuca sativa* L., when used concentrations of 7 a 15% (CERVERA-MATA et al., 2019). Indicating that decomposition processes such as composting can contribute to the reduction of allelopathic substance contents, thus, future studies are needed to evaluate the species under field conditions and the mixture of the residue with other products or after the composting process.

Conclusion

The residue from the coffee roasting process has an allelopathic effect on maize, soybeans and cowpea, with a more pronounced effect on maize.

Even at the lowest concentration of residue (2%), a reduction in the physiological quality of seeds and seedling biometry was observed.

Interest conflicts

There was no conflict of interest for the authors.

Author contributions

Maria da Conceição Freitas Moura – conducting work, writing and reading; Lucas Kennedy Silva Lima – conducting the work and statistical analysis; Alek Sandro Dutra – guidelines, corrections and text revision; Eveline Nogueira Lima – conducting work and reading.

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