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Sorghum seed coating with zinc: Physiological quality and initial performance of plants

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ABSTRACT. Sorghum (*Sorghum bicolor*) is highly sensitive to zinc deficiency in soils, which results in decreased productivity and low-quality agricultural products. Our objective was to evaluate the effects of different zinc doses, applied to seeds, on the physiological quality and initial performance of sorghum plants. Six doses (0, 3.5, 7.0, 14.0, 21.0, and 28.0 g kg^{-1} seeds) were used and an uncoated control. The Zn coating process used dolomitic limestone as the filler and glue. Laboratory tests were conducted in a completely randomized design and greenhouse experiments were conducted in a randomized block design. The control means were 8, 9, and 14% lower than the maximum, minimum, and total seed area of treatments, respectively, relative to that of treatments. The control differed from other treatments by 10.47 in the speed index of emergence. Zinc at a dose of 28 g kg^{-1} seeds provided greater production of aerial dry matter, with nutrient content of 75.85 mg kg^{-1}. Zinc on sorghum seeds affected length and dry matter production of aerial parts and roots but did not affect physical characteristics, germination, or emergence time. Applied zinc accumulated mainly in the roots, and promotes changes in Ca and Mg in seeds and other plant parts.

Keywords: *Sorghum bicolor*; micronutrients; dry matter; ICPE-9000; Groundeye®.

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Introduction

Sorghum (*Sorghum bicolor*) is a crop of great importance in the national agricultural sector because of its agronomic characteristics, which allow its cultivation in succession during the off-season (Diniz, Batista, Borges, & Silveira, 2018). As a cereal, sorghum grain has essentially the same nutritional properties as corn and is used for the same purposes. However, under favorable water conditions, corn has a greater productive potential than does sorghum. Nonetheless, regarding a second crop with greater climatic risk, the potential of both crops is equal, especially during late sowing, making sorghum cultivation more attractive because of greater tolerance to water deficits, good performance in marginal areas, and lower production cost (Ribas, 2014).

However, similar to other annual crops, sorghum is responsive to good agricultural and management practices, such as liming and fertilization, especially when seeking high levels of productivity (Borges et al., 2016). Regarding micronutrients, sorghum plants are highly sensitive to zinc deficiencies, which is the micronutrient most limiting to crop production. Despite being required in small quantities, zinc is essential for the growth and reproduction of plants and has important roles in metabolism, being necessary as a structural component of a large number of proteins, in addition to participating in the biosynthesis of indole acetic acid (AIA; Marschner, 2012).

Zinc deficiency is very common in many types of soil, especially in tropical regions with highly weathered soils. This deficiency impairs the physiological functions of plants leading to a severe reduction in growth, in addition to compromising productivity and resulting in low-quality agricultural products (Sadeghzadeh, 2013).

In areas with low zinc content in the soil, fertilization with this micronutrient is an important agricultural practice to guarantee maximum production in sorghum crops; however, the quantities required by this cereal are low and this makes a uniform application in the field difficult. An efficient application of zinc could be conducted via a seed coating technique, which could guarantee better uniformity, lower application costs, and place the nutrient close to the seedling root system, ensuring nutrition during the initial stage of growth when the root system is poorly developed. In addition to the initial advantages of the coating, which increases seed size, altering the shape and texture of the seeds in such a way that reduces the loss of time in manual and mechanized planting (Romualdo & Rozane, 2008; Acha, Vieira, Souza, & Silva, 2018).

Therefore, it is important to evaluate the effects of the application of zinc via seeds, to avoid the use of inappropriate doses that could be toxic and adversely affect the physiological potential of the seeds, as well as the development of plants in the field (Prado & Mouro, 2007). Thus, the objective of this work was to evaluate the effects of the application of different doses of zinc on the physiological quality and initial performance of grain sorghum plants.

Material and methods

The experiment was conducted from January to March 2019, under laboratory and greenhouse conditions, adopting a completely randomized design and randomized blocks, respectively. Commercial grain sorghum seeds (hybrid PR40G34) were used and were coated with six doses of zinc sulfate ($ZnSO_4$; 0, 3.5, 7.0, 14.0, 21.0, and 28.0 g kg^{-1} seeds). Uncoated seeds served as the control treatment.

The seed coating process was conducted using an adaptation of the methodology of Xavier, Vieira, and Guimarães (2015), using an N10 Newpack coater equipped with a stainless steel bowl with speed regulation, spray pressure control, which sprayed the cement material, and a drying system. The coater was adjusted such that the steel vat rotated at a speed of 86 rpm with a pressure of 4 bar compressed air, which activated the cement solution for 3 s. Then, a hot air fan was turned on and the temperature reached 50°C for 90 s. For coating, dolomitic limestone was used as a filling material and glue based on polyvinyl acetate (PVA) diluted in water that was previously heated to 70°C. The cement material had a proportion of 3:1 (water to glue, respectively).

Four repetitions of the coating process were conducted per treatment of 100 g of seeds each. A 100 g portion of seeds was placed in the coater vat, the spray of the adhesive solution was applied for 3 s, and then a portion of filling material (initially 10 g of material) was added to the vat. Next, another spray of adhesive solution (3 s) was applied followed by another portion of the filling material (10 g of material) was added to the seeds with another application of adhesive solution (3 s). Next, the air blower (50°C) was activated for 90 s. This procedure resulted in the first coating layer. For the next layer, a jet of the adhesive solution was applied followed by a portion of filler material, and then another jet of the adhesive solution was accompanied by a second portion of filler material. Finally, another jet of the adhesive solution was applied, before triggering the final hot air, which again lasted 90 s. This procedure was repeated until 200 g of filling material was used, totaling 10 layers of the coating by the end of this process. The doses of zinc sulfate ($ZnSO_4$) were added in one application during the fifth coating layer, between the portions of dolomitic limestone and glue.

After the coatings, seeds were evaluated for physical and physiological characteristics and nutritional content. The physical evaluations were performed in the laboratory and consisted of the seed biometrics determined by the Seed Analysis System (Groundeye®) using four replications of 50 seeds for each treatment. The extracted variables included the maximum diameter (MAD), minimum diameter (MID), and total seed area (TA), with all results expressed in cm.

The physiological evaluations performed in the laboratory included the: 1) germination test (G), which was conducted with four repetitions of 50 seeds, using a germ-coated paper roll moistened with a volume of water equivalent to 2.5 times the weight of the dry substrate as the test substrate. After sowing, the rolls were kept in a germinator at 20-30°C under a photoperiod of 16 hours darkness and 8 hours light. The evaluations were conducted on the 10th day after sowing, and the percentage of normal seedlings was recorded (Brasil, 2009); 2) germination speed index (GSI), which was conducted with the G test, with daily counts performed after the start of the test. The seedlings that showed normal characteristics according to Brasil (2009) were considered germinated for the calculation of the GSI and the formula proposed by Maguire (1962) was used; and 3) accelerated aging (AA) test, in which a gearbox was used with a metallic mesh fixed in the middle position, with 40 mL of distilled water in the bottom of each gerbox, and a uniform layer of seeds from each treatment distributed over the mesh and covering the surface of the canvas, constituting a single layer. Then, the boxes containing the seeds were covered and placed in a BOD type incubator, at 41°C, where they remained for 72 hours (Marcos-Filho, 2016). After this period, the seeds were submitted to the germination test, as previously described. The evaluation was conducted 7 days after sowing, and the results were expressed as a percentage.

The characteristics evaluated in the greenhouse included: 1) emergence (E), which was conducted in 8 L pots containing previously washed sand. Four replications of 50 seeds were used, distributed in furrows 3 deep and 2 cm apart. The substrate was moistened whenever necessary until it reached field capacity and at 15, 30, and 45 days after sowing, 500 mL of complete 25% nutrient solution, without Zn, was applied to each pot. The final evaluation of the seedlings was conducted at 60 day after sowing; 2) emergence speed index (ESI), which was conducted with the E test. The ESI was determined by the daily recording of the number of seedlings that emerged with the coleoptiles above the substrate, from the beginning until the 30° day after sowing. To calculate the ESI, the formula proposed by Maguire (1962) was used.

At the end of the E test, 10 plants from each experimental unit were selected, separating the aerial part from the root, where the length of both parts was measured with the aid of a millimeter ruler. Subsequently, they were stored in paper bags and placed in an air circulation oven at 65°C for 72 hours to determine the dry mass of both parts.

The nutrient content present in the seeds and other plant parts of each treatment was determined after a drying period of 72 hours (at a temperature of 65°C). After drying, the seeds were macerated and the aerial part and root were ground and placed in hermetically sealed tubes. To determine the levels of calcium, magnesium, and zinc, the material underwent digestion with nitrates and the extract was analyzed using the ICPE-9000 (Acha et al., 2018).

The data obtained were subjected to analysis of variance and Dunnett's test at a 5% probability to compare the treatment means (combinations of the coating with Zn doses) with that of the control. Regression analysis was used to access the doses.

Results and discussion

Variables evaluated in the laboratory

There was no effect of zinc doses (Zn) for the variables MAD, MID, TA, GSI, and G; thus, the regression was not significant (Table 1).

When analyzing the physical variables, it was observed that the control treatment presented means 8, 9 and 14% lower for MAD, MID, and TA, respectively, in relation to that of the treatments (Table 1). These results were caused by the coating process that adhered to the filling material (dolomitic limestone) and Zn to the surface of the seeds, thereby resulting in a change in the shape of the seeds and explaining the higher values for the physical variables (Figure 1). Thus, the first objective of the coating process was achieved because the shape and size of the seed were improved and modified, which should provide greater precision in sowing and the application of chemicals (Acha, Vieira, & Freitas, 2016).

Table 1 shows that the coating on the seeds increased the physical variables analyzed (MAD, MID, and AT); however, for some treatments, there was no statistical difference in the parameters in relation to the values for the control. Similar results were found by Acha et al. (2016), who observed that the use of doses of zinc and boron in the coating of perennial soybean seeds impaired the physical quality of the coating because as the doses increased, the adhesiveness of the coating decreased.

Regarding the physiological variables, Table 1 shows that the GSI for control was significantly greater than that of all treatments. This result was mainly caused by the additional physical barrier formed around the seeds by the coating, which hindered the exchange process between the seeds and the external environment, consequently, delaying the germination process and initial seedling development. These results are in agreement with those of several authors (Xavier et al., 2015; Acha et al., 2016), who reported that coated seeds take longer to germinate than uncoated seeds because of the coating.

Table 1. Maximum diameter (MAD), minimum diameter (MID), total area (TA), germination speed index (GSI), and germination (G) of graniferous sorghum seeds, depending on zinc doses (g kg^{-1}).

Treatment	Variables Evaluated				
	MAD	MID	TA	GSI	G
	(cm)		(cm^2)		(%)
Control	0.475	0.425	0.162	24.12	80.00
0.0	0.520*	0.465	0.193*	19.37*	82.75
3.50	0.515	0.450	0.182	19.05*	83.00
7.0	0.522*	0.467	0.190	21.15*	84.50
14.0	0.523*	0.483*	0.195*	20.68*	84.00
21.0	0.515	0.472*	0.190	20.29*	85.50
28.0	0.505	0.457	0.183	20.22*	80.50
Test F	0.8927^{ns}	0.3910^{ns}	0.8096^{ns}	0.1641^{ns}	0.6708^{ns}
Linear regression	ns	ns	ns	ns	ns
Quadratic regression	ns	ns	ns	ns	ns

*, ^{ns}: significant result and non-significant by the test F the 5%, respectively. *Averages with an asterisk in the column differed from that of the control at 5% probability according to the Dunnett's test.

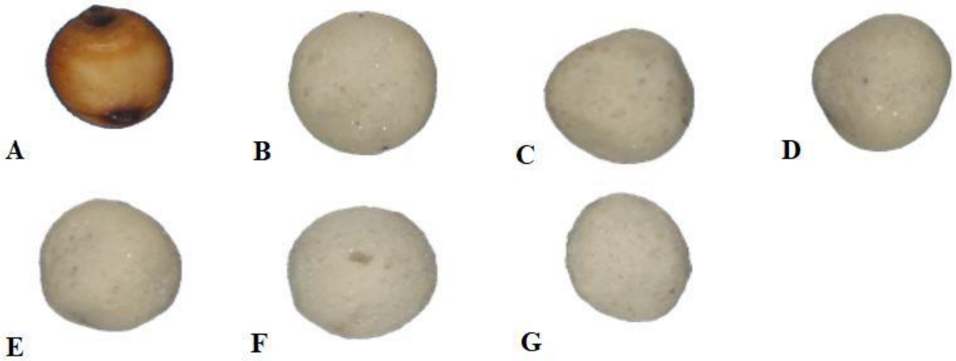

Figure 1. Sorghum seeds: A) Intact seed; B) Dolomitic limestone coating; C) Dolomitic limestone + 3.5 g kg^{-1} Zn; D) Dolomitic limestone + 7.0 g kg^{-1} Zn; E) Dolomitic limestone + 14.0 g kg^{-1} Zn; F) Dolomitic limestone + 21.0 g kg^{-1} Zn; and G) Dolomitic limestone + 28.0 g kg^{-1} Zn.

In the G test, the coated seeds did not differ from that of the control and these results corroborated those of Funguetto, Pinto, Baudet, and Peske (2010), who worked with rice seeds treated with Zn sources, and found no significant difference in the germination of treated seeds with those of the control. On the other hand, Yagi et al. (2006) working with zinc-treated sorghum seeds observed a reduction in the percentage of germination with increasing Zn doses. Although there was no significant difference with that of the control, the coated seeds showed numerically higher germination percentages, with averages ranging from 80.5 to 85.5% (Table 1), being above the minimum recommended germination standard for the commercialization of hybrid sorghum seeds, which is 80%. These results corroborated those of Slaton, Wilson, Ntamatungiro, Norman, and Boothe (2001), who observed that the application of Zn doses on rice seeds increased the germination percentage.

The germination of the coated seeds (Table 1) indicated that although the coating constitutes an additional barrier, which directly affected initial seedling development, the application of zinc acted beneficially in germination. This may have been caused by the action of zinc as an activator of a series of enzymes, such as dehydrogenases, aldolases, and isomerases, which intensify respiration, and consequently, the production of ATP for processes that require energy, such as germination (Marschner, 2012). Zinc is considered an element that accelerates the growth of the radicle and plays an important role in the initial growth of seedlings (Cakmak, 2005).

Figure 2 shows that Zn doses significantly influenced AA, with increasing linear behavior with an increase of 0.28%. This beneficial effect may be associated with the fact that a large amount of Zn present in the seeds could have protective effects on the radicle and contribute to tolerance to abiotic stresses, in addition to activating important enzymes for plant metabolism (Cakmak, 2005). These results corroborate those of Lemes et al. (2017) who treated soybean seeds with different doses of zinc, which caused an increase in the percentage of normal seedlings in the AA test up to the dose of 3.1 mL kg^{-1} of seeds for lot A and 1.8 mL kg^{-1} of seeds for lot B.

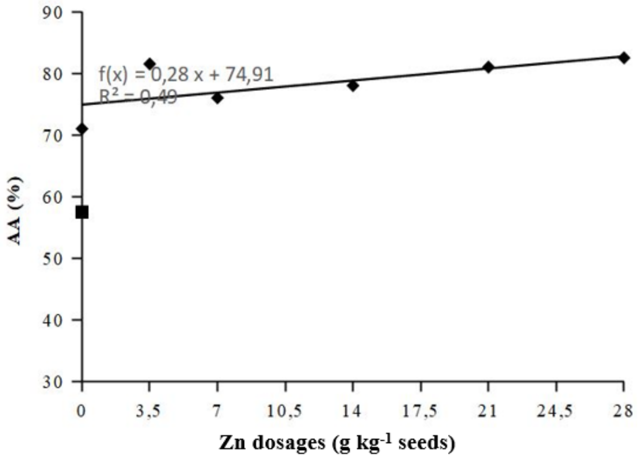

Figure 2. Effects of the application of zinc doses on grain sorghum seeds submitted to accelerated aging (AA) test.

Additionally, coating with dolomitic limestone also had a positive effect on the vigor of the sorghum seeds, because regardless of the applied Zn dose, all coated seeds obtained normal seedling averages with numerical values above that observed for the control seeds, which was 57.50% (Figure 2).

Variables evaluated in the greenhouse

For the ESI and E tests, there was no effect of zinc doses (Table 2).

Table 2. Emergence speed index (ESI) and emergence (E) of graniferous sorghum seeds, as a function of zinc doses (g kg^{-1}).

Treatment	Variables Evaluated	
	ESI	E
	(%)	
Control	10.47	89.00
0.0	5.91*	8700
3.5	6.26*	91.00
7.0	6.27*	89.00
14.0	6.73*	84.00
21.0	6.12*	93.00
28.0	6.58*	86.00
F test value	0.7904^{ns}	0.1681^{ns}
Linear regression	^{ns}	^{ns}
Quadratic regression	^{ns}	^{ns}

*, ^{ns}: significant result and non-significant by the F test at 5%, respectively. *Averages with an asterisk in the column differed from that of the control at 5% probability according to Dunnett's test.

In the ESI test, it was observed that all treatments differed significantly from the control according to the Dunnett's test. This result reaffirmed that observed for the GSI test (Table 1) where the coating formed seeds with an additional barrier, delaying seedling emergence. Similar results were observed by Acha et al. (2018) and Silva, Vieira, Baroni, Maitan, and Acha (2017), who observed a delay in the emergence of perennial soybeans and coated styling seeds, respectively.

The E variable showed that treatments did not differ from that of the control. These results were beneficial to the culture. Although the coating providing an outer layer to the integument and zinc interfered in the water potential around the seed, these factors did not affect the emergence of sorghum plants in the greenhouse. Tavares et al. (2015), evaluating the effects of different doses of zinc in the treatment of seeds of two barley cultivars, found no differences between the doses used, which were similar to that of the controls in the emergency test.

Regarding the aerial part length (APL), root length (RL), aerial part dry mass (APDM), and dry root mass (DRM), significant effects of Zn doses were observed (Figure 3).

In the length of the aerial part, quadratic behavior was observed with the point of maximum efficiency for the dose of 25.70 g kg^{-1} of seed, reached a length of 63.80 cm, reducing this variable in higher doses (Figure 3). These results corroborated those of Lemes et al. (2017), who worked with soybean seeds treated with different doses of zinc, and found that APL showed quadratic behavior with maximum efficiency for the dose of 5 mL Zn kg^{-1} of seeds, with this variable declining with higher doses. Furlani, Furlani, Meda, and Duarte (2005) observed significant effects of Zn on the length of corn plants, with variable responses depending on the cultivar, and this effect could be positive at low concentrations and in some cases negative at high concentrations of the nutrient.

However, considering the values of Zn sufficiency in the aerial part of sorghum plants (23 to 39 d after sowing), suggested by Lockman (1972), < 30, 30-60, and > 60 mg kg^{-1} for levels low, normal, and high, respectively, the levels of Zn in the aerial part of the plants in this study were, therefore, considered sufficient to supply the needs of the plants.

The RL also presented a quadratic behavior, with the maximum efficiency observed for the dose of 10.61 g kg^{-1} of seed, with roots reaching a length of 44.87 cm. With increasing doses, a decrease in this effect was observed. The increase in RL was caused by the fact that zinc plays an important role in plant metabolism, participating in the synthesis of the amino acid tryptophan, a precursor of AIA, which is the main growth-promoting hormone, in addition to activating several enzymes and being a structural component of others (Sadeghzadeh, 2013). However, doses of zinc greater than 10.61 g kg^{-1} seed were toxic to the roots causing inhibition of root elongation, which is a characteristic parameter of zinc toxicity (Marschner, 2012).

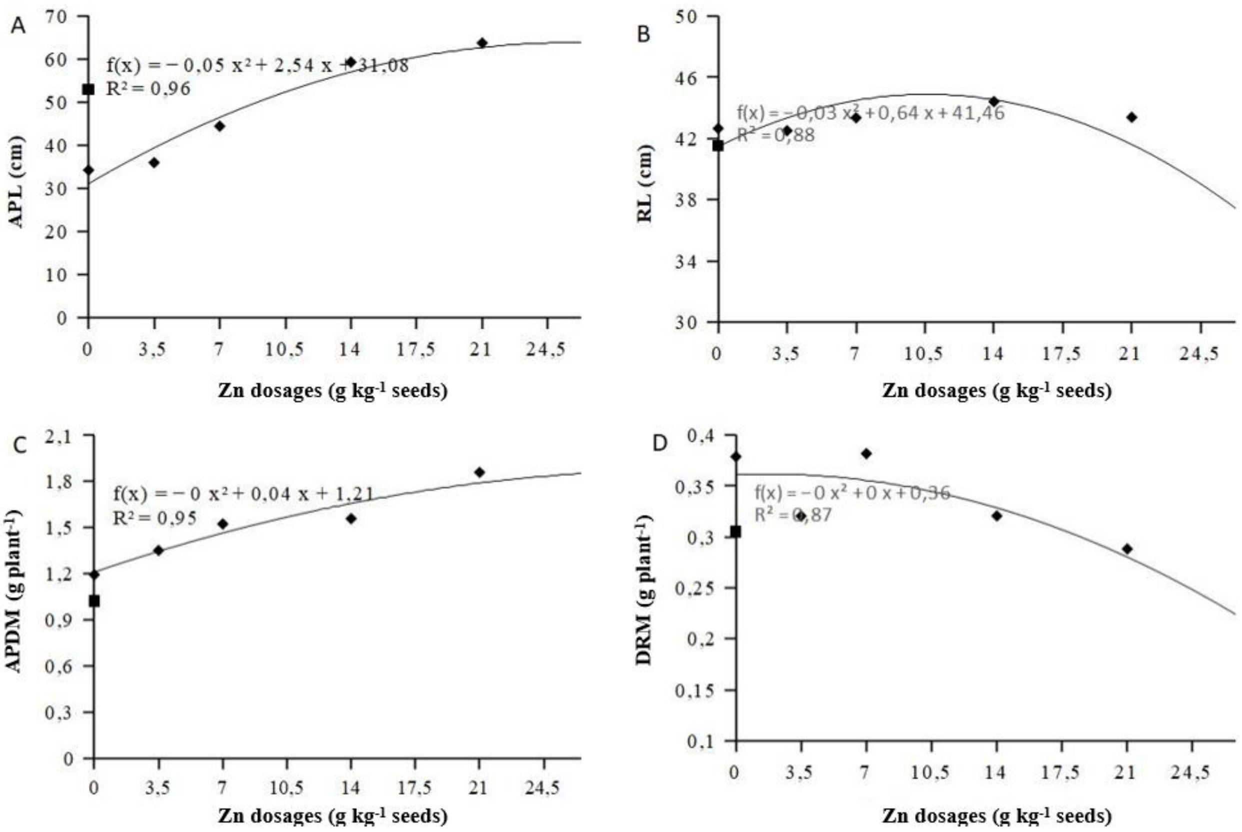

Figure 3. Effects of the application of doses of zinc on grain sorghum seeds on the length of the aerial part (A), length of the root (B), dry mass of the aerial part (C), and dry mass of the root (D).

In the APDM variable, it was observed that the model that best fit the data was quadratic, reaching 1.85 g plant^{-1} for the highest tested dose (28 g kg^{-1} of seeds; Figure 3). Similar results were observed by Slaton et al. (2001) and Rozane, Prado, Romualdo, and Simões (2008) who observed increases in APDM production while working with the application of Zn doses to rice seeds.

In the production of DRM, decreasing quadratic behavior was observed, with a maximum point of 0.3616 g plant^{-1} observed at a dose of 1.75 g kg^{-1} of seeds. The decreasing effect observed in the DRM could be related to the decreasing effect observed in RL (Figure 3) because the length of the roots directly influenced the absorption of nutrients and contributed to a representative proportion of the total dry mass-produced. These results corroborated those of Prado and Mouro (2007) and Romualdo and Rozane (2008) who reported a decreasing quadratic effect in the production of DRM with the treatment of sorghum seeds with doses of Zn in the form of sulfate.

It was observed that the applied Zn doses significantly affected the Zn levels in the seeds, aerial parts, and roots of sorghum. Regarding the Zn content present in the seeds, a quadratic effect of Zn doses was observed, reaching 2120 mg kg^{-1} at the highest dose used (28 g Zn kg^{-1}). For the control seeds and seeds coated only with dolomitic limestone, Zn contents of 16 and 20 mg kg^{-1} were observed, respectively (Figure 4).

According to Rashid and Fox (1992) under conditions of the sufficiency of the other nutrients, content above 10 mg kg^{-1} of Zn in sorghum seeds was sufficient to avoid limitation in crop production. Thus, the seeds that were not treated with zinc presented the minimum levels able to promote the initial development of the sorghum seedlings, as observed in the variables G (Table 1) and D (Table 2) where no difference occurred between seeds regardless of treatment.

For the aerial part, an increasing linear behavior was observed with an increase of 0.63 mg kg^{-1} of Zn for each unit increase in the applied zinc dose (Figure 4). It was observed that at the maximum dose used (28 g Zn kg^{-1}) the Zn content in the aerial part was 75.85 mg kg^{-1}. Although sorghum plants had increasing levels of Zn in the aerial part, the values in this study were much lower than those of Yagi et al. (2006), Prado and Mouro (2007), and Romualdo and Rozane (2008), who used a dose of 28 g Zn kg^{-1} and had contents of 209.32, 1331.08, and 846.98 mg kg^{-1}, respectively, in their studies on the application of Zn in sorghum seeds.

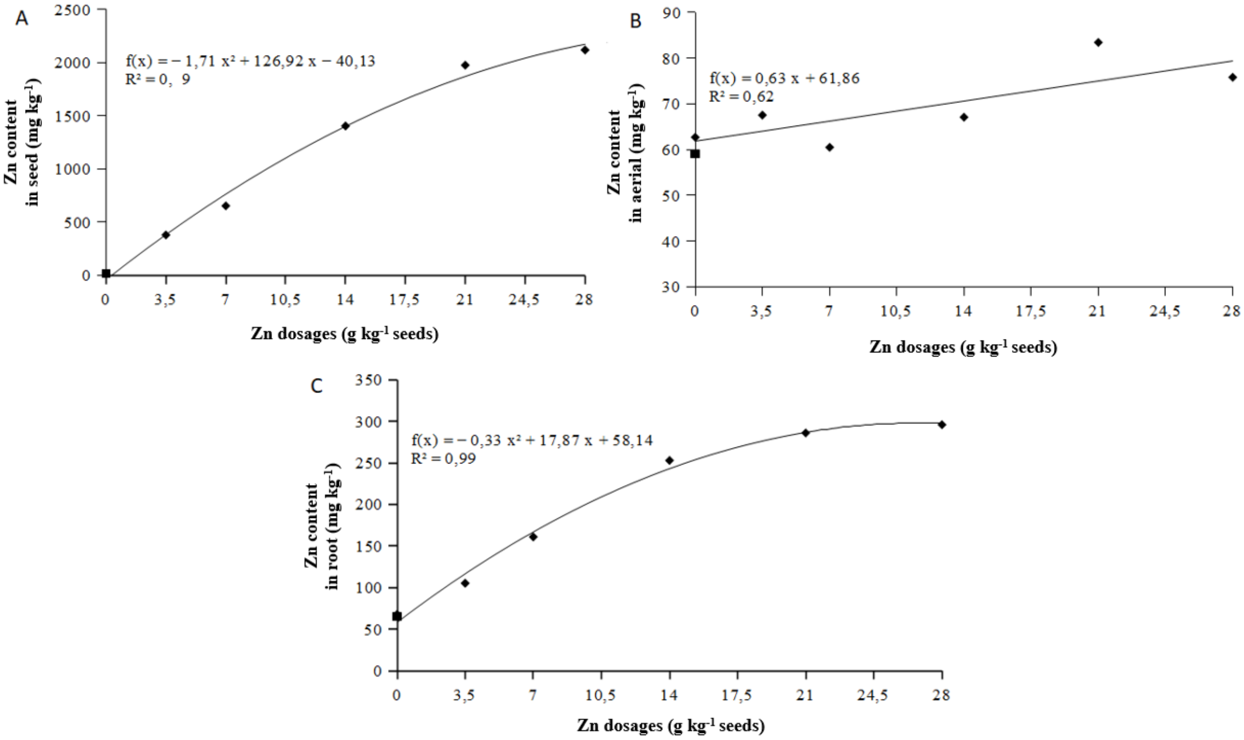

Figure 4. Effects of the application of doses of zinc on grain sorghum seeds on the zinc content in the seed (A), in the aerial part (B), and the root (C).

It is worth mentioning that in this study the micronutrient was incorporated into the seed together with the filling material (dolomitic limestone) by the coating process, which may have interfered the absorption and subsequent translocation of zinc in the plant, whereas the other studies cited dealt with seeds using the method in which moistened zinc adhered directly to the seed. Additionally, plant genotypes vary widely in terms of tolerance and Zn deficiency; both in terms of utilization and absorption, even efficient Zn genotypes with greater absorption capacity do not necessarily have a higher concentration of Zn in leaves or sprouts (Sadeghzadeh, 2013).

There was a quadratic effect for Zn doses on root contents, with a maximum content of 298.10 mg kg^{-1} of Zn at a dose of 26.88 g of Zn kg^{-1} of seeds (Figure 4). These results corroborate those of Yagi et al. (2006) who worked with the application of Zn doses in sorghum seeds and observed a quadratic effect with a maximum content of 315 mg kg^{-1} of Zn at a dose of 21.70 g of Zn kg^{-1} of seeds.

Similar to other studies (Yagi et al. 2006; Rozane et al., 2008), a higher proportion of Zn in the roots was observed in relation to the aerial part, which may be characterized by the effect of accumulation of the nutrient in this part of the plant. The greater accumulation of Zn in the roots compared to the aerial part occurs because the root acts as a barrier for this element, and reduces the possibility of toxicity in the plant. Thus, it is a tolerance mechanism of the cultivar to high doses of the nutrient. It should be noted that the tolerance of plants to excess Zn is related to the plant exude chelating substances in the roots, which act by binding the metal to the charges on the cell wall or by the complexation of the metal (Zn) in the cytoplasm of the cells by organic and inorganic acids, phytates, and phytoquelatins (Wang & Evangelou, 1994). Thus, the formed compounds are stored in vacuoles in the least toxic form for the plant, but in the chemical analysis of plant tissue, this is quantified by inferring high nutrient content in the plant.

Given the above, the higher concentration of Zn in the roots directly inferred the decrease in the length and production of DRM (Figure 3) observed in this work because the accumulation of Zn in the roots was strictly correlated with the decrease of their length and amount of dry matter (Longnecker & Robson, 1993).

The application of Zn significantly affected the accumulation of the nutrients calcium and magnesium. There was a linear effect on the accumulation of nutrients studied in the seeds, the aerial part, and root, except for Ca in the aerial part (Figure 4). The results obtained for Mg content of the aerial part and root, despite being significant, did not fit the linear or quadratic regression models (Table 3).

In Table 3, the relationship of the nutrients accumulated in the aerial part, only at the dose of 21 g kg^{-1} of Zn, did the levels of Ca and Mg differ significantly from the levels present in the control, according to Dunnett's test. Thus, in general, sorghum plants absorbed Ca and Mg in the aerial part close to the critical content to supply the need for plant development. Thus, levels were close to those observed for plants in the control.

Regarding the content of Mg accumulated in the root, the treatment with the dose of 21 g kg^{-1} did not differ significantly from that of the control. This may have been related to the Mg content present in the aerial part, indicating there was a balance in the accumulation of nutrients in relation to plant parts (Table 3).

With increasing doses of Zn, there was a decrease in the accumulation of Ca and Mg by sorghum seeds (Figure 5).

Similar results to those shown for the seeds in Figure 4, were observed by Acha et al. (2016) working with perennial soybean seeds coated with dolomitic limestone and different doses of boron and zinc. The authors attributed this result to the granulometry of the material used in the coating because zinc sulfate has larger and heavier particles, whereas dolomitic limestone is finer. In this way, limestone should be added in the layers closest to the core, such that its adhesion to the surface of the seeds is guaranteed because of its weight; however, when placing the zinc sulfate between the limestone layers it was not possible to maintain adhesiveness of the layers because of its crystallized shape, thereby, reducing the adhesion of limestone, and consequently, reducing the levels of Ca and Mg.

Table 3. Calcium and magnesium content present in the aerial part and roots of the plants, as a function of zinc doses (g kg^{-1}).

Treatment	Variables Evaluated		
	Aerial part		Root
	Ca	Mg	Mg
		(mg kg^{-1})	
Control	6.003	3.835	0.8776
0.0	7.870	4.603	2.751*
3.50	7.805	3.900	4.370*
7.0	6.962	4.508	2.435*
14.0	6.752	4.200	2.333*
21.0	8.942*	6.115*	2.053
28.0	8.577	4.297	2.975*
Test F	0.2693^{ns}	0.0156*	0.0081*
Linear regression	^{ns}	0.1529^{ns}	0.1108^{ns}
Quadratic regression	^{ns}	0.3805^{ns}	0.0900^{ns}

*, ^{ns}: significant result and non-significant by the F test at 5%, respectively. *Averages with an asterisk in the column differed from that of the control at 5% probability according to the Dunnett's test.

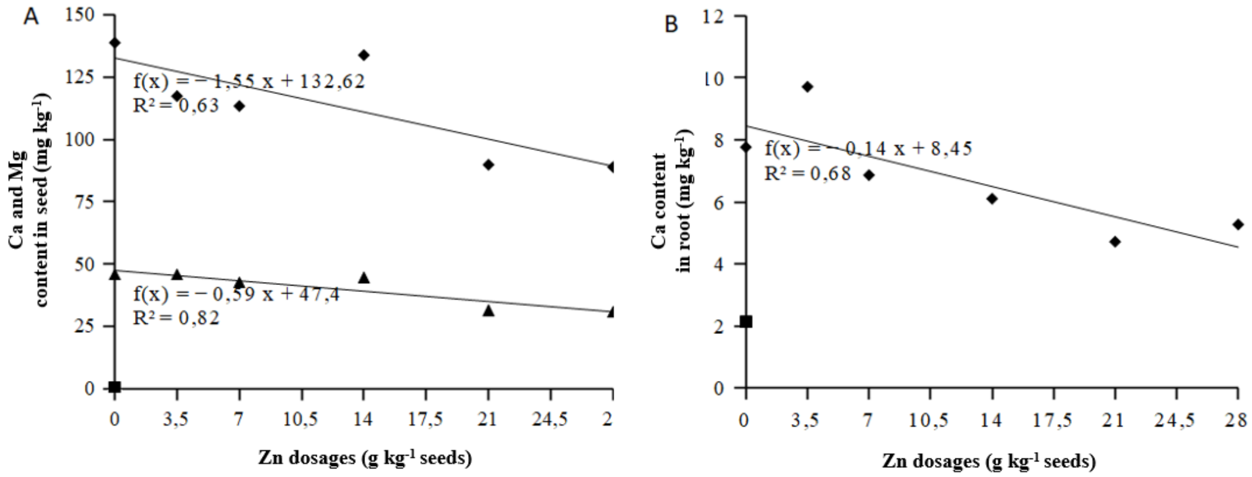

Figure 5. Effects of the application of zinc doses on the calcium and magnesium content in the seed (A) and the root (B).

In Figure 5, there was a decrease in the Ca content in the roots as the doses of Zn increased; this may have been related to the decrease in the Ca content present in the seeds. The decrease in Ca content may have contributed to the evolution of symptoms of Zn toxicity, because, in addition to being a constituent nutrient of the cell wall, Ca is also required for cell stretching and division, and this is dramatically reflected in root growth (Marschner, 2012).

Conclusion

The application of zinc to the sorghum seeds affected the length and dry matter production of the aerial parts and roots of the plants; however, it did not affect the physical characteristics or the germination and emergence of the coated seeds. The zinc applied to the sorghum seeds accumulated mainly in the roots. The doses of zinc applied promoted changes in the content of the nutrients Ca and Mg in seeds and other parts of plants.

References

Acha, A. J., Vieira, H. D., & Freitas, M. S. M. (2016). Perennial soybean seeds coated with high doses of boron and zinc. *African Journal of Biotechnology, 15*(37), 1998-2005. DOI: https://doi.org/10.5897/AJB2016.15560

Acha, A. J., Vieira, H. D., Souza, C. L. M., & Silva, F. W. A. (2018). Methodology of applying different doses of boron and zinc in the coating of perennial soybean seeds. *Journal of Experimental Agriculture International, 26*(5), 1-9. DOI: https://doi.org/10.9734/JEAI/2018/43968

Borges, I. D., Franco, A. A. N., Kondo, M. K., Martins, D. C., Teixeira, E. C., & Moreira, S. G. (2016). Acúmulo de macronutrientes na cultura do sorgo granífero na safrinha. *Revista Brasileira de Milho e Sorgo, 15*(2), 294-304. DOI: http://dx.doi.org/10.18512/1980-6477/rbms.v15n2p294-304

Brasil. (2009). *Regras para análise de sementes*. Brasília, DF: Mapa/ACS.

Cakmak, I. (2005). Effect of micronutrients on seed quality. In C. J. Li, F.-S. Zhang, A. Doberman, P. Hinsinger, H. Lambers, X. L. Li, ... Y.-G. Zhu (Eds.), *Plant nutrition for food security, human health and environmental protection* (p. 34-35). Beijing, CN: Tsinghua University Press.

Diniz, G. M. M., Batista, R. O., Borges, I. D., & Silveira, H. M. (2018). Período anterior à interferência de plantas daninhas em sorgo granífero e forrageiro. *Revista Brasileira de Milho e Sorgo, 15*(3), 470-480.

Funguetto, C. I., Pinto, J. F., Baudet, L., & Peske, S. T. (2010). Desempenho de sementes de arroz irrigado recobertas com zinco. *Revista Brasileira de Sementes, 32*(2), 117-123. DOI: https://doi.org/10.1590/S0101-31222010000200014

Furlani, Â. M. C., Furlani, P. R., Meda, A. R., & Duarte, A. P. (2005). Eficiência de cultivares de milho na absorção e utilização de zinco. *Scientia Agricola, 62*(3), 264-273. DOI: https://doi.org/10.1590/S0103-90162005000300010

Lemes, E. S., Mendonça, A. O., Dias, L. W., Brunes, A. P., Oliveira, S., Fin, S. S., & Meneghello, G. E. (2017). Tratamento de sementes de soja com zinco: efeito na qualidade fisiológica e produtividade. *Colloquium Agrariae, 13*(2), 76-86. DOI: https://doi.org/10.5747/ca.2017.v13.n2.a162

Lockman, R. B. (1972). Mineral composition of grain sorghum plant samples. *Communications in Soil Science and Plant Analysis, 3*(4), 295-303. DOI: https://doi.org/10.1080/00103627209366379

Longnecker, N. E., & Robson, A. D. (1993). Distribution and transport of zinc in plants. In A. D. Robson (Ed.), *Zinc in soils and plants* (p. 79-91). Dordrecht, NL: Springer.

Maguire, J. D. (1962). Speed of germination-aid in selection and evaluation for seedling emergence and vigor. *Crop Science, 2*(2), 176-177.

Marcos-Filho, J. (2016). *Seed physiology of cultivated plants* (2nd ed.). Londrina, PR: ABRATES.

Marschner, P. (2012). *Mineral nutrition of higher plants* (3rd ed.). Oxford, GB: Elsevier.

Prado, R. M., & Mouro, M. C. (2007). Fontes de zinco aplicado em sementes de sorgo cv. BRS 310 e o crescimento inicial. *Semina: Ciências Agrárias, 28*(3), 355-364. DOI: http://dx.doi.org/10.5433/1679-0359.2007v28n3p355

Rashid, A., & Fox, R. L. (1992). Evaluating internal zinc requirements of grain crops by seed analysis. *Agronomy Journal, 84*(3), 469-474. DOI: https://doi.org/10.2134/agronj1992.00021962008400030022x

Ribas, P. M. (2014). Origem e importância econômica. In A. Borém, L. D. Pimentel, & R. Parrela (Eds.), *Sorgo: do plantio à colheita* (p. 9-36). Viçosa, MG: UFV.

Romualdo, L. M., & Rozane, D. E. (2008). Aplicação de zinco em sementes de sorgo cv. BRS 304: efeitos na nutrição e no crescimento inicial. *Acta Scientiarum. Agronomy, 30*(4), 471-478. DOI: https://doi.org/10.4025/actasciagron.v30i4.5300

Rozane, D. E., Prado, R. M., Romualdo, L. M., & Simões, R. R. (2008). Resposta de plântulas de arroz cv. BRS-Soberana à aplicação de zinco via semente. *Ciência e Agrotecnologia, 32*(3), 847-854. DOI: https://doi.org/10.1590/S1413-70542008000300022

Sadeghzadeh, B. (2013). A review of zinc nutrition and plant breeding. *Journal of Soil Science and Plant Nutrition, 13*(4), 905-927. DOI: http://dx.doi.org/10.4067/S0718-95162013005000072

Silva, F. W. A., Vieira, H. D., Baroni, D. F., Maitan, M. Q., & Acha, A. J. (2017). Germination performance of Campo Grande (*Stylosanthes capitata* / macrocephala) Stylers seeds coated with different layers of inert material. *Journal of Experimental Agriculture International, 18*(4), 1-8. DOI: https://doi.org/10.9734/JEAI/2017/36768

Slaton, N. A., Wilson, C. E., Ntamatungiro, S., Norman, R. J., & Boothe, D. L. (2001). Evaluation of zinc seed treatments for rice. *Agronomy Journal, 93*(1), 152-157. DOI: https://doi.org/10.2134/agronj2001.931152x

Tavares, L. C., Brunes, A. P., Rufino, C. A., Fonseca, D. Â. R., Gadotti, G. I., & Villela, F. A. (2015). Tratamento de sementes de cevada com zinco: potencial fisiológico e produtividade de sementes. *Semina: Ciências Agrárias, 36*(2), 585-594. DOI: http://dx.doi.org/10.5433/1679-0359.2015v36n2p585

Wang, J., & Evangelou, V. P. (1994). Metal tolerance aspects of plant cell wall and vacuole. In M. Pessarakli (Ed.)*, Handbook of plant and crop physiology* (p. 695-717). Tucson, AZ: University of Arizona.

Xavier, P. B., Vieira, H. D., & Guimarães, C. P. (2015). Physiological potential of stylosanthes cv. Campo Grande seeds coated with different materials. *Journal of Seed Science, 37*(2), 117-124. DOI: https://doi.org/10.1590/2317-1545v37n2145982

Yagi, R., Simili, F. F., Araújo, J. C., Prado, R. M., Sanchez, S. V., Ribeiro, C. E. R., & Barretto, V. C. M. (2006). Aplicação de zinco via sementes e seu efeito na germinação, nutrição e desenvolvimento inicial do sorgo. *Pesquisa Agropecuária Brasileira, 41*(4), 655-660. DOI: https://doi.org/10.1590/S0100-204X2006000400016