ASIAN J TROP BIOTECHNOL
Volume 19, Number 2, December 2022
Pages: 45-51

ISSN: 0216-6887
E-ISSN: 2301-8658
DOI: 10.13057/biotek/c190201

Antioxidant potential of ginger extract on metals (lead, cadmium, and boron) induced oxidative stress in maize plant

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Manuscript received: 8 April 2022. Revision accepted: 18 July 2022.

Abstract. *Ezeonu CS, Tatah SV, Imo C, Yakubu OE, Garba QH, Arowora K, Umaru IJ, Abah MA, Abu MS, Yohanna ER, Timothy M. 2022. Antioxidant potential of ginger extract on metals (lead, cadmium, and boron) induced oxidative stress in maize plant. Asian J Trop Biotechnol 19: 45-51.* Plants have a high potential to accumulate heavy metals, which may have a toxic effect on them. These heavy metals can induce the generation of reactive oxygen species in plants which may affect their physiological activities. This research aimed to examine ginger extract's antioxidant potential in treating metals (lead, cadmium, and boron) in contaminated soil in which maize was cultured. Maize seedlings were grown in pots containing soil (A-H) induced with lead acetate, cadmium, and boron (1 g each) and treated with 1 g of ginger extract, simulated for 40 days. The uptake and distribution of the heavy metals (lead, cadmium, boron) with possible induction of oxidative stress alteration in the activity of the antioxidant defense system of the maize plants were determined. The inhibitory effect of ginger against lead, cadmium, boron induced oxidative stress in maize seedlings was also determined, and the percentage inhibition showed an increase in extract concentration of ginger. From the result, maize seedlings grown from 10-40 days with 1 g of lead, 1 g of cadmium, and 1 g of boron showed significant ($p<0.05$) increased lipid peroxidation in the whole maize plant compared to the control. However, ginger extract caused a significant ($p<0.05$) decrease in the accumulation of lipid peroxide concentration in the seedlings. In addition, there was a marked increase in antioxidant enzyme activities in the lead, cadmium, and boron-contaminated soil. The result also showed that lead, cadmium, and boron-induced oxidative stress in maize seedlings could be ameliorated by ginger extract and antioxidant enzymes, which are the biomarkers for metal-induced oxidative stress in maize plants. The result obtained showed a significant ($P<0.05$) increase in SOD activity in maize seedlings grown in pots B and G (15.95±1.34 nmol/mg and 15.85±0.49 nmol/mg, respectively); B and C (10.70±1.14 nmol/mg and 10.95±0.07 nmol/mg, respectively) and A and H on the soils contaminated with 1 g lead, cadmium, and boron, respectively. SOD activity was observed to be higher in pots E (28.47±1.65 nmol/mg) and H (21.29±1.12 nmol/mg) (boron contaminated soil) when compared with lead and cadmium contaminated soils. The study has clearly shown that lead, cadmium, and boron toxicity induces oxidative stress in maize plants which the ginger antioxidant effect could reduce.

Keywords: Antioxidant enzymes, ginger extract, maize plant, metals, oxidative stress

INTRODUCTION

Naturally, heavy metals are contaminants and pollutants to plants, humans, and the environment because of their persistence, high toxicity, and easy transmission through the food chain. These metals are widely spread in the air, water, and soil and easily enter living organisms (Kim et al. 2015; Irawati et al. 2017; Tatah et al. 2017). As a result, heavy metals often coexist in soil and plant systems. The buildup of heavy metals in soils can restrict soil function, result in toxicity to plants, and contaminate the food chain by affecting food quality and safety (Van Bussel et al. 2014). Because most plant roots are located in the soil, they play important roles in the absorption of heavy metals (Topolska et al. 2014). In a soil environment, they inhibit seed germination, stunt seedling growth, and threaten plant metabolic reactions for proper growth and development, resulting in low yields (Kasfori and Petrovic 2008). High levels of heavy metals in soils normally result in oxidative damage to plants either directly or indirectly by triggering an increased level of reactive oxygen species generation that generally causes damage to biological molecules such as proteins, membrane lipids, chloroplast pigments, enzymes, nucleic acids, etc. (Malecka et al. 2001). These free radicals include superoxide radical (O_2^{*-}), hydroxyl radical (OH^{*-}), and hydrogen peroxide (H_2O_2) that are produced as by-products during membrane-linked electron transport reactions and by associated metabolic pathways (Khaki et al. 2009). Oxidative stress occurs when there is an imbalance between the production of reactive oxygen species and the biological system's ability to readily detoxify the reactive intermediates produced or failure to easily repair the damages caused (Halliwell 1994; Ojochenemi et al. 2019).

Maize (*Zea mays* L.) is an edible flowering plant in the Gramineae family and is a warm-season crop that is easily grown during the spring and summer. Additionally, maize serves as the main food source for humans and animals around the world. It is considered one of the main cereal crops of West Africa. It is the fourth most consumed cereal in Nigeria in the past two decades, after sorghum, millet, and rice. Maize is the world's highest supplier of calories, with a caloric supply of about 19.5%. It provides more calories than rice (16.5%) and wheat (15.0%) (Badu-Apraku et al. 2021). It is one of the most important staple foods in the world today. Maize is also the most important staple food in Nigeria, and it has grown to be the local 'cash crop' most especially in the south-western part of Nigeria, where at least 30% of the cropland has been devoted to small-scale maize production under various cropping systems (Badu-Apraku et al. 2021). Maize can also be used in animal feed as a feedstock source (Zhema et al. 2022). To meet the ever-increasing demand for maize for both domestic consumption and the export market, farmers are now employing different methods of farming, such as the application of fertilizers, pesticides, compost manure, and irrigation to improve and protect the maize (Abah et al. 2021). However, agricultural practices such as applying phosphatic fertilizers, pesticides, and refuse-derived composts contribute to heavy metals in the soil (Wang and Sun 2013; Okoli et al. 2021). Because the roots of maize plants are located in the soil, they can absorb heavy metals, which accumulate in the plant's tissues over time, resulting in oxidative damage to plants either directly or indirectly (Hechmi et al. 2015). However, Ginger (*Zingiber officinale* Roscoe) which has been reported to be a strong antioxidant substance, can mitigate or prevent a generation of free radicals. It is considered a safe herbal medicine with few and insignificant side effects (Ali et al. 2008). Ginger and its constituents are stated to have antiemetic, antithrombotic, anti-hepatotoxic, anti-inflammatory, stimulant, cholagogue, androgenic and antioxidant properties (Khaki et al. 2009). This research is aimed at assessing the absorption and distribution of heavy metals (lead, cadmium, and boron) in the root and shoot of maize plants which induced oxidative stress and to determine the inhibitory potential of ginger as well as a possible alteration in the activity of some defensive enzymes of maize plants.

MATERIALS AND METHODS

Collection of soil sample

Soil samples were collected randomly from different locations within Federal University Wukari, Taraba State, Nigeria, to be induced with metal ions.

Collection of ginger rhizomes

Ginger rhizomes were collected from the Wukari market region, Taraba State, Nigeria, before being transported to the Biochemistry Laboratory, Federal University Wukari, Taraba State, Nigeria.

Preparation of ginger extracts

Ginger rhizomes were reduced into smaller pieces, and the rhizomes were dried at a certain temperature in an air oven for 7 days. Then, the rhizomes were ground and sieved through a mesh of fine size to obtain a powdered sample of whole ginger. The powdered ginger sample (500 g) was extracted via maceration in ethanol for a period of 48 hrs using the method described by Aguawa and Mittal (1981), modified by Tugbobo et al. (2018).

Experimental design

Maize seeds were surface sterilized with hypochloric acid solution (0.1%) for 10 mins and then rinsed with distilled water before planting. After 24 hrs of inhibition of seeds in water (seed priming), the seedlings were raised in pots. The pots were grouped in which some were treated with metals and ginger extract, while others served as control before planting the seeds. Optimum relative humidity for 12 hrs photoperiod was maintained. The pots were formed into (8) groups: A, B, C, D, E, F, G, and H. Three plants were used in each treatment as biological replicates. (i) Pot A: 2 kg of soil microcosm treated with 1 g ginger extract as a positive control. (ii) Pot B: 2 kg of soil microcosm only served as normal control. (iii) Pot C: 2 kg of soil microcosm contaminated with 1 g of lead acetate. (iv) Pot D: 2 kg of soil microcosm contaminated with 1 g of cadmium. (v) Pot E: 2 kg of soil microcosm contaminated with 1 g of boron. (vi) Pot F: 2 kg of soil microcosm contaminated with 1 g of lead and treated with 1 g of ginger extract. (vii) Pot G: 2 kg of soil microcosm contaminated with 1 g of cadmium and treated with 1 g of ginger extract. (viii) Pot H: 2 kg of soil microcosm contaminated with 1 g of boron and treated with 1 g of ginger extract. The seeds were then sown and allowed to germinate in pots (A-H) for 40 days. Germinated seeds were then observed in a secured environment.

Determination of metallic contents (lead, boron, and cadmium) in maize seedlings

Metallic contents in maize seedlings were determined using the atomic absorption spectrometry (AAS) method as described by Tugbobo et al. (2018). A fresh whole plant sample was collected and surface sterilized with 1ml of HCl acid and then with 1 mM Na2EDTA for the surface-bound metal ions under study and then dried in an oven at 50ºC for 3-days. Dried samples were mashed into a fine powder using a blender and then mixed with concentrated H_2SO_4. Mixed samples were dissolved in de-ionized distilled water, and the metal content (lead, boron, and cadmium) was determined.

Determination of anti-oxidant potentials of ginger

The antioxidant activity of ginger in maize was determined using the method described by Ohkawa et al. (1979) and modified by Tugbobo et al. (2018). The whole plant was pounded in cold saline (1/10 w/v) with 10 up-and-down strokes in mortar and pestle. The homogenate was centrifuged for 10 min at 10,000 x g to obtain the supernatant and incubated with the different metal ions under study (boron, cadmium, and lead) and ginger extract at varied concentrations together with de-ionized water at a total volume of 300 µL at 37ºC for 1 hr. The color reaction was monitored by adding 200 µL, 250 µL, and 500 µL each of 8.1% Sodium Dodecyl Sulfate (SDS) and acetic acid at pH 3.4 and 0.6% TBA, respectively. The solution was incubated at 97ºC for 1 hr, and absorbance was read at 532 nm.

Oxidative stress assay

The level of lipid peroxidation products was determined using the Heath and Packer (1968) method. Fresh root and shoot samples were ground in 0.25% thiobarbituric acid (TBA) in 10% TCA using a mortar and pestle. The mixture was heated at 95ºC for 30 minutes, cooled in an ice bath, and centrifuged at 10,000 x g for 10 minutes. The absorbance of the supernatant was read at 532 nm, while a total of 0.25% TBA in 10% TCA served as the blank. The concentration of lipid peroxides and the oxidative-modified proteins of plants were quantified and expressed as total TBARS as mol/g^{-1} fresh weight using an extinction coefficient of 155 mM^{-1} $cm^{-1.}$

Preparation of plant extract for antioxidant enzyme assays

The fresh leaves (500 mg) from the stressed plants were ground into a fine powder with liquid nitrogen. The powdered samples were homogenized with 1.2 mL of 0.2 M potassium phosphate buffer (pH 7.8), followed by centrifugation at 14,000 g for 20 minutes at 4ºC. Then, the supernatant was removed, and the pellet was re-extracted again. The collected supernatants were stored at 4℃ for various antioxidant enzyme assays.

Superoxide dismutase assay

Superoxide dismutases are metalloproteins that occur in different isoforms with different metal co-factors. The activity of Superoxide Dismutase (SOD) was determined by calculating the reduction in the absorbance of formazone formed by the reaction between the superoxide and dye (Nitrobluetetrazolium (NBT)) by the enzymes (Dhinda et al. 1981). Fifty (50) nM phosphate (pH 7.8), 2 nM ethylenediaminetetraacetic acid (EDTA), 9.9 nm L-Methionine, 55 nm NBT and 0.025% triton-X were freshly prepared before the estimation. The extract was filtered and centrifuged at 22,000 x g for 10 mins at 4ºC. Test tubes were arranged, and 1 mL of phosphate buffer, 20 µL of EDTA, 100 µL of L-Methionine, 10 µL Triton X-100, 10 µL Riboflavin, 20 µL of plant extract, and lastly, 1.2 mL of NBT have added accordingly, and mixture without plant extract served as the control. The absorbance of samples was recorded at 475 nm using the UV-visible spectrophotometer. The enzyme activities were expressed as units/ mg of protein.

Catalase (CAT) assay

Catalase is mostly present in the cytosol and peroxisomes that catalyze H_2O_2 and O_2. Therefore, the catalase activity was examined by the Beers and Sizer method (1982). First, the homogenate was centrifuged at 22,000 x g for 10 mins at 4ºC, after which the supernatant was used for the enzyme assay. The assay mixtures include the plant extract, 100 nM potassium buffer (7.0), and 75 nM hydrogen peroxide. Then the absorbance was measured at 240 nm using a UV-Visible spectrophotometer. Finally, the catalase activity was assayed using an extinction coefficient of 39.4 mM^{-1} cm^{-1}.

Glutathione reductase assay

Glutathione reductase is an NADPH enzyme, and it catalyzes oxidized glutathione (GSSG) into reduced form (GSH). The co-factor for GR is flavin adenine dinucleotide (FAD) and cysteine, which are present in chloroplast, cytosol, and mitochondrial. Glutathione reductase was assayed by Schaedle and Bassham's (1997) method. The assay mixture was freshly prepared, consisting of 0.75 mM DTNB, 0.1 mM NADPH, 1 mM GSSG, and 10 µL crude plant extract. GSSG was finally added to the assay mixture to increase the adsorption at 340 nm. The activity was calculated using the extinction coefficient of 6.2 mM^{-1} Cm^{-1}.

Statistical analysis

The data were analyzed using statistical package for social science (SPSS) software version 23, and the group means were compared for significance at p≤ 0.05. Data were presented as mean ± standard deviation.

RESULTS AND DISCUSSION

Metals uptake by growing maize seedlings in soil microcosm for 40 days (mg/kg)

Figures 1, 2, and 3 show the uptake of metals by soil microcosm for 40-days by the growing maize seedlings. The highest level of maize seedling absorption of lead (86. 32 mg/kg) in pot C, cadmium (74.42 mg/kg) in pot G, and boron (85.45 mg/kg) in pot H was observed on day 40, and the least level of lead, cadmium and boron absorption (20.20 mg/kg) were observed on day 10 in pot A.

Level of lipid peroxidation

Figures 4, 5, and 6 show the total oxidative stress in the growth of the maize plant for 40 days. The results obtained in these tables showed an increase in the production of lipid peroxides in maize plants with their maximum and minimum levels on days 10 and 40, respectively.

Inhibitory potential of ginger extract

Figure 7 shows the inhibitory potential of ginger extract in metal-induced oxidative stress on maize plants. 160 mg/mL of the ginger extract showed the highest inhibitory potential on lead (84%) and the lowest inhibitory potential on boron (52%). Ten (10) mg/mL of the ginger extract showed the highest inhibitory potential on lead (16%) and the lowest inhibitory potential on cadmium (14%).

SOD enzyme activity in maize grown in metals-contaminated soil with and without ginger treatments

Figures 8, 9, and 10 show the effect of heavy metal (lead, cadmium, and boron) uptake on superoxide dismutase activity in pre and post-ginger extract-treated soil in maize seedlings. The result obtained in Figures 8, 9, and 10 showed a significant ($P<0.05$) increase in SOD activity in maize seedlings grown in pots B and G (15.95±1.34 nmol/mg and 15.85±0.49 nmol/mg, respectively); B and C (10.70±1.14 nmol/mg and 10.95±0.07 nmol/mg, respectively) and A and H on the soils contaminated with 1 g of lead, cadmium, and boron, respectively.

Catalase enzyme activity in maize grown in metal-contaminated soil with and without ginger treatments

Figures 8, 9, and 10 also shows the effect of heavy metals (lead, cadmium, and boron) uptake on catalase activity in pre and post-ginger extract treatment in maize plant. For catalase (CAT) activity, it was observed that maize seedlings grown on boron-contaminated soil pots H (0.99±0.02 nmol/mg) were significantly ($P<0.05$) lower than the normal control (B) that was grown on lead (1.08±0.08 nmol/mg), cadmium (1.98±0.12 nmol/mg) and boron (1.24±0.06 nmol/mg). However, in pots F (3.99±0.01 nmol/mg) and G (2.96±0.93 nmol/mg) treated with the sample extract, CAT activity was appreciably higher in maize plant tissues when compared to control.

Glutathione reductase enzyme activity in maize grown in metals-contaminated soil with and without ginger treatments

Figures 8, 9, and 10 show the effect of heavy metals (lead, cadmium, and boron) uptake on glutathione reductase activity in pre and post-ginger extract treatment in maize plants. Glutathione Reductase (GR) activity was observed to be higher in pots treated with lead acetate (C), cadmium (D), and boron (E) when compared with normal control (B). Similarly, GR activity was significantly ($P<0.05$) higher in pot A treated with extract on maize seedlings growing in pots F2.70±0.42 nmol/mg), G (1.98±0.28 nmol/mg), and H (1.89±0.14 nmol/mg).

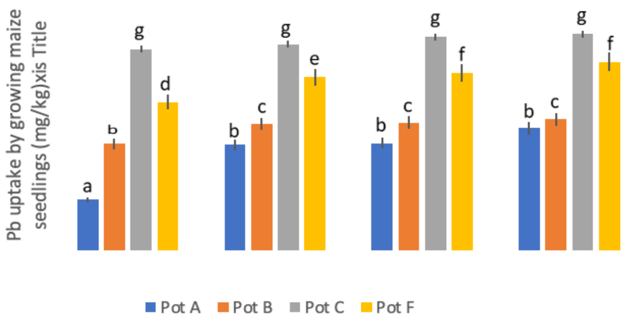

Figure 1. Lead uptake by growing maize seedlings (mg/kg)

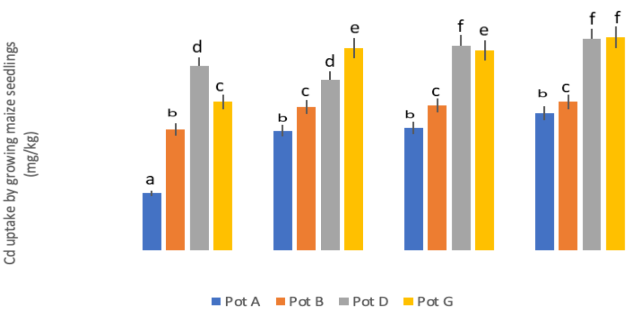

Figure 2. Cadmuim uptake by the growing maize seedlings (mg/kg)

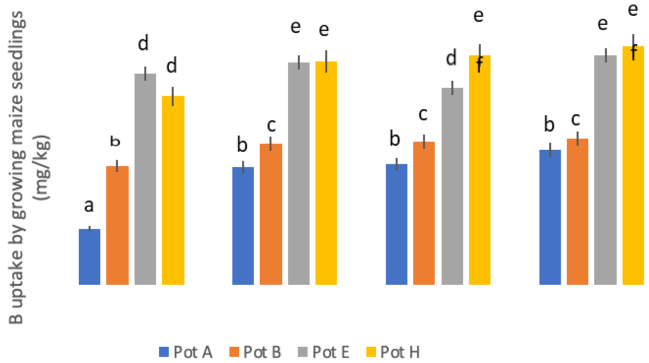

Figure 3. Boron uptake by growing maize seedlings (mg/kg)

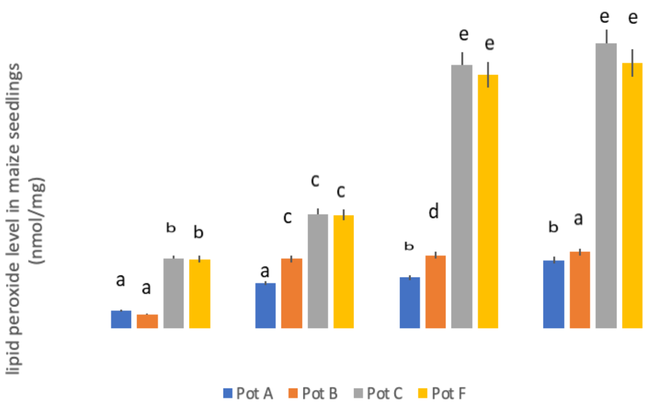

Figure 4. Level of lipid peroxide in maize seedlings with and without lead contamination (nmol/mg). Note: n=2, results are shown as mean values ± SD. Values with different superscripts are significantly different ($p<0.05$)

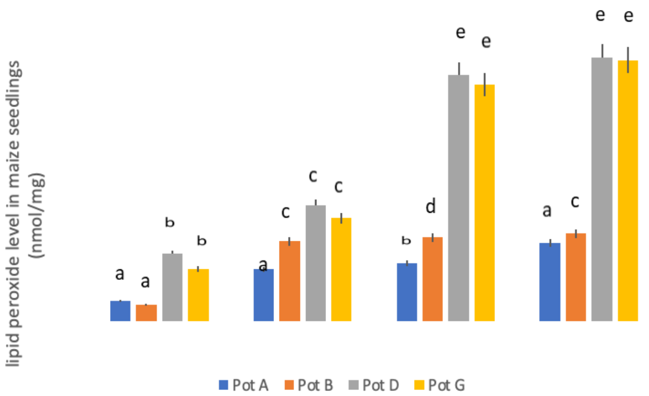

Figure 5. Level of lipid peroxide in maize seedlings with and without cadmium contamination (nmol/mg). Note: n= 2, results are shown as mean values ± SD. Values with different superscripts are significantly different ($p<0.05$)

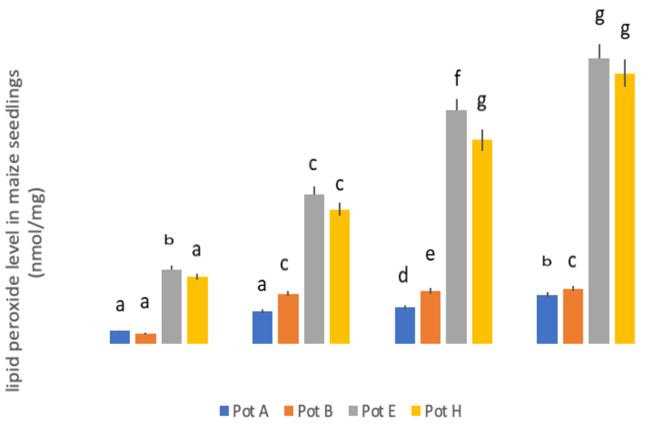

Figure 6. Level of lipid peroxide in maize seedlings with and without boron contamination (nmol/mg). Note: n= 2, results are shown as mean values ± SD. Values with different superscripts are significantly different (p<0.05)

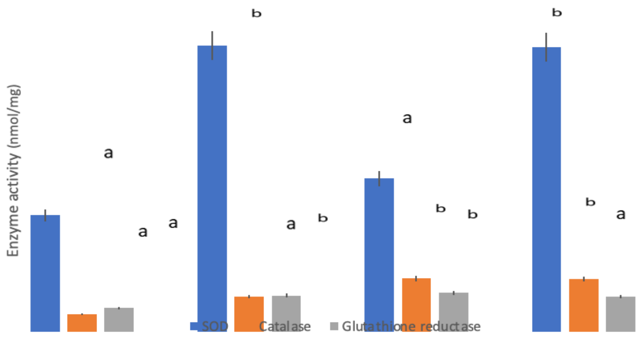

Figure 9. SOD, Catalase and Glutathione enzyme activity in maize grown in cadmium contaminated soil with and without ginger treatments (nmol/mg). Note: n= 2, results are shown as mean values± SD. Values with different superscripts are significantly different (p<0.05)

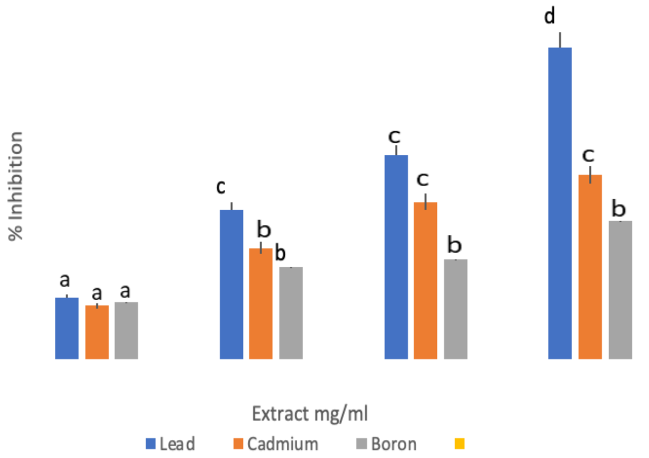

Figure 7. Inhibitory potential of ginger extract on metals (lead, cadmium, boron) induced oxidative stress in maize grown on 2 kg of soil (group B)

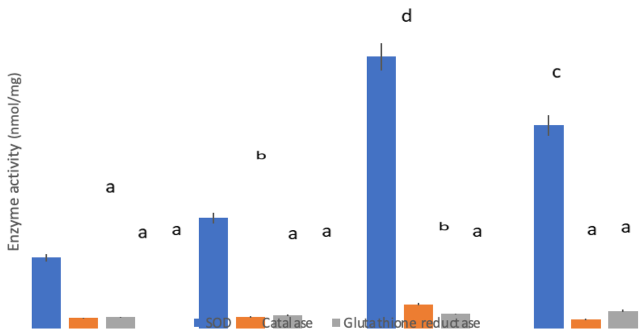

Figure 10. SOD, Catalase and Glutathione enzyme activity in maize grown in boron contaminated soil with and without ginger treatments (nmol/mg). Note: n= 2, results are shown as mean values ± SD. Values with different superscripts are significantly different (p<0.05)

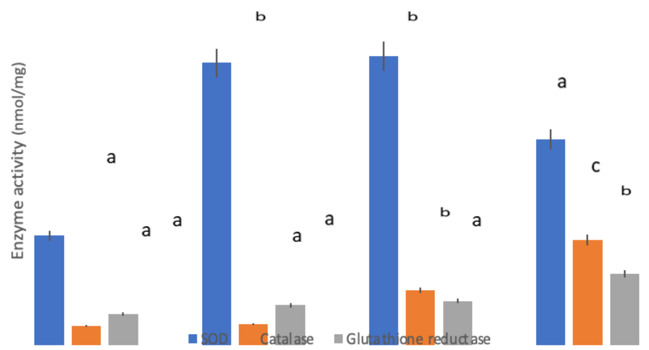

Figure 8. SOD, Catalase and Glutathione enzyme activity in maize grown in lead acetate contaminated soil with and without ginger treatments (nmol/mg). Note: n= 2, results are shown as mean values± SD. Values with different superscripts are significantly different (p<0.05)

Discussion

The contamination of ecosystems and exposure to toxic metals is a significant worldwide burden. For this reason, bio-monitoring techniques are getting more relevant because they may help recognize contaminated areas or crops, distribute metals in the ecosystem, and control potential environmental hazards caused by heavy metals pollution (Ugulu 2015).

Figures 1, 2, and 3 show the uptake of metals by soil microcosm for 40-days by the growing maize seedlings. The highest level of maize seedling absorption of lead (86. 32 mg/kg) in pot C, cadmium (74.42 mg/kg) in pot G, boron (85.45 mg/kg) in pot H was observed on day 40, and the least level of lead, cadmium and boron absorption (20.20 mg/kg) were observed on day 10 in pot A. The increase of these heavy metals in maize plants based on their age could result from the constant interaction between the metal and the root of the plant (maize) through their concentration in the soil (Rosselli et al. 2006). However, comparing pots with contamination of heavy metals and when 1 g of ginger extract was used in treating soils contaminated with metals, the reducing absorption of metal by maize plants was possible except for cadmium and boron, perhaps due to the chelating ability of the ginger extract on soil metals thus increasing the antioxidant potential in the maize plants by reducing the metals available for absorption or absorption of the ginger extract by maize seedling thereby increasing the antioxidant potentials in maize plants as explained by Tanvir et al. (2017).

Figures 4, 5, and 6 show the total oxidative stress in the growth of the maize plant for 40 days. The results obtained in these tables showed an increase in the production of lipid peroxides in maize plants with their maximum and minimum levels on days 10 and 40, respectively. The accumulation in lipid peroxides levels could be due to an increase in the retention of heavy metals by the roots of the maize plants. However, pots that were treated with 1 g of ginger extract per 2 kg of soil microcosm (pots F, G, and H) showed a decrease in the level of lipid peroxides when compared with pots contaminated with 1 g of metals per 2 kg of soil microcosm only (pots C, D, and E). The increase in the level of lipid peroxides in pots C, D, and F could be attributed to the ability of the heavy metals to catalyze one electron (e-) transfer reaction that generates reactive oxygen species, thereby generating more lipid peroxides (Lozano et al. 1996). Therefore, the decrease in the level of lipid peroxides in pots F, G, and H could be attributed to the preventive effect demonstrated by ginger due to the presence of ginger constituents, which enhances its antioxidant activity, as reported by Tanvir et al. (2017).

Antioxidants can decrease oxidative damage directly by reacting with free radicals or indirectly by inhibiting the activity or expression of free radical generating enzymes or enhancing the activity or expression of intracellular antioxidant enzymes (Tanaka et al. 1985). From the result presented in Figure 7, the inhibitory potential of ginger extract in metal-induced oxidative stress on maize plants could be possible due to the hydrogen donating ability of ginger extract. The percentage inhibition shows an increase with an increase in extract concentration of ginger.

Plants generally possess an essential antioxidant defense system used naturally to combat oxidative damage. Figures 8, 9, and 10 show the effect of heavy metal (lead, cadmium, and boron) uptake on superoxide dismutase activity, catalase activity, and glutathione reductase activity in pre and post ginger extract treated soil in maize seedlings. The result obtained in Figures 8, 9, and 10 showed a significant ($P<0.05$) increase in SOD activity in maize seedlings grown in pots B and G (15.95±1.34 nmol/mg and 15.85±0.49 nmol/mg, respectively); B and C (10.70±1.14 nmol/mg and 10.95±0.07 nmol/mg, respectively) and A and H on the soils contaminated with 1 g of lead, cadmium, and boron respectively. Therefore, SOD activity was observed to be higher in pots E (28.47±1.65 nmol/mg) and H (21.29±1.12 nmol/mg) (boron contaminated soil) when compared with lead and cadmium contaminated soils. This possibly may be because boron is absorbed more by maize plants than lead and cadmium. Hence, excessive boron reduces the defensive potential of SOD in maize plants. SOD activity has been reported to increase under heavy metal toxicity, and this increase in response to stress could be due to de novo synthesis of the enzyme (Lozano et al. 1996).

Figures 8, 9, and 10 also shows the effect of heavy metals (lead, cadmium, and boron) uptake on catalase activity in pre and post-ginger extract treatment in maize plant. For catalase (CAT) activity, it was observed that maize seedlings grown on boron-contaminated soil pots H (0.99±0.02 nmol/mg) were significantly ($P<0.05$) lower than the normal control (B) that was grown on lead (1.08±0.08 nmol/mg), cadmium (1.98±0.12 nmol/mg) and boron (1.24±0.06 nmol/mg). However, in pots F (3.99±0.01 nmol/mg) and G (2.96±0.93 nmol/mg) treated with the sample extract, CAT activity was appreciably higher in maize plant tissues when compared to control. Catalase activity is an antioxidant enzyme responsible for the degradation of hydrogen peroxide. Therefore, the decline in CAT activity in pots D, F, and G could be attributed to lead, cadmium, and boron toxicity, respectively which could delay the removal of hydrogen peroxide and peroxides mediated by catalase which in turn enhances free radical-mediated lipid peroxidation in maize plant.

Figures 8, 9, and 10 show the effect of heavy metals (lead, cadmium, and boron) uptake on glutathione reductase activity in pre and post-ginger extract treatment in maize plants. Glutathione Reductase (GR) activity was observed to be higher in pots treated with lead acetate (C), cadmium (D), and boron (E) when compared with normal control (B). Similarly, GR activity was significantly ($P<0.05$) higher in pot A treated with extract on maize seedlings growing in pots F2.70±0.42 nmol/mg), G (1.98±0.28 nmlo/mg), and H (1.89±0.14 nmol/mg). The increased GR activity suggests a possible involvement of GR in regenerating Glutathione (GSH) from Glutathione (GSSG) under lead toxicity to increase the GSH/GSSG ratio and thus, increase the total glutathione pool (Noctor and Foyer 1998).

In conclusion, the study has clearly shown that lead, cadmium, and boron toxicity induces oxidative stress in maize plants which the ginger antioxidant effect could reduce. In contrast, antioxidant enzymes play a pivotal role in combating plant oxidative stress.

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