

RESEARCH ARTICLE

Effect of Different Concentrations of Copper (Cu) on Growth Attributes and Bioaccumulation in *Celosia argentea* and *Amaranthus hybridus*

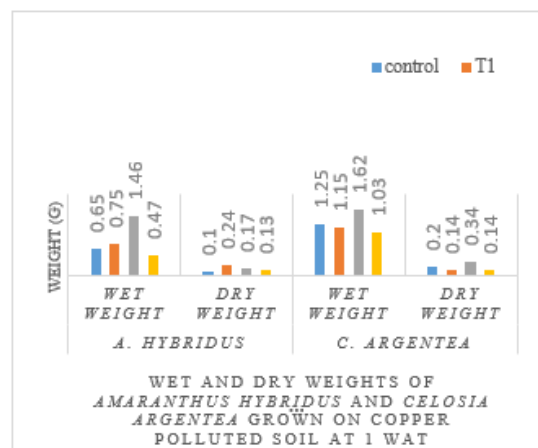
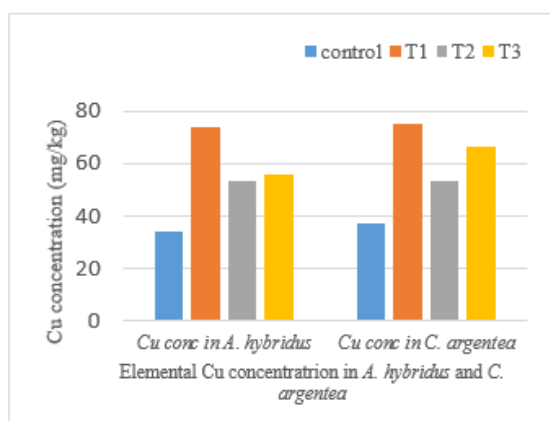
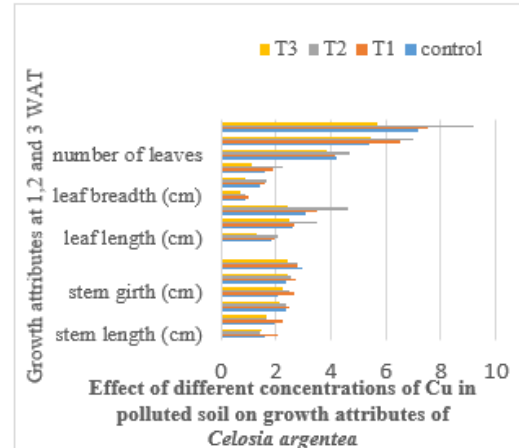
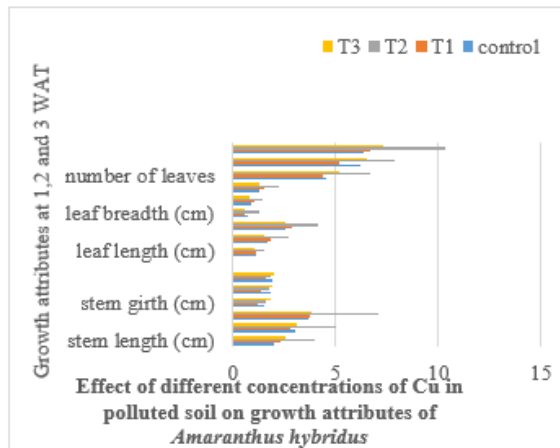
K.G. Olawepo, A.S. Oluwatobi*, D.R. Awotunde and P.O. Fatoba

*Amaranthus hybridus*

This study was carried out to investigate the growth performance and bioaccumulation of copper (Cu) in *Amaranthus hybridus* and *Celosia argentea* planted in Cu polluted soil.

Seedlings of the vegetables were transplanted into pots containing soil pretreated with different concentrations of Cu - 100, 200 and 400 mg/kg; denoted as T₁, T₂ and T₃ respectively, and a control pot without Cu pollution.

Growth attributes of the vegetables, elemental Cu bioaccumulated, and wet and dry weights were examined.



Highlights

- *Amaranthus hybridus* and *Celosia argentea* are two commonly consumed vegetables in Nigeria
- Vegetables are cultivated in polluted environments due to the perceived fertility of the soil
- Cu addition to the soil improved most of the growth attributes of *A. hybridus* when the concentration is not greater than 200 mg/kg
- *Celosia argentea* bioaccumulated more Cu at 100 mg/kg, and expressed retardation in its growth attributes when grown in soil with higher concentration

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Effect of Different Concentrations of Copper (Cu) on Growth Attributes and Bioaccumulation in *Celestia argentea* and *Amaranthus hybridus*

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Abstract: Cultivation of vegetables in polluted soil has been on the increase following the perceived fertility of such soil. This study investigated the growth performance and bioaccumulation of copper (Cu) in *Amaranthus hybridus* and *Celosia argentea* planted in Cu polluted soil. The research was conducted at the University of Ilorin botanical garden. Vegetable seedlings were transplanted into soil pots pre-treated with Cu - 100, 200 and 400 mg/kg; denoted as T₁, T₂ and T₃ respectively, and a control pot without Cu treatment. *Amaranthus hybridus* grown in soil polluted with 200 mg/kg of Cu gave the highest stem length at 1, 2 and 3 weeks after transplanting (WAT) i.e., 3.98, 5.00 and 7.05 cm respectively. There was no significant difference in stem girth and leaf length and breadth of *Celosia argentea* grown in 200 mg/kg Cu (P<0.05). However, leaf length and breadth and number of leaves were significantly higher (P<0.05) in *C. argentea* grown in soil with same Cu concentration at 3 WAT i.e., 4.63 cm, 2.27 cm and 9.17 respectively. Bioaccumulation pattern recorded in *A. hybridus* indicated that those grown in soil polluted with 100 mg/kg of Cu have the highest elemental Cu accumulation (73.77 mg/kg). *Amaranthus hybridus* and *Celosia argentea* recorded highest wet and dry weights in those planted in soil polluted with 200 mg/kg of Cu.

Keywords: *Amaranthus*; Bioaccumulation; *Celosia*; Copper; Pollution

INTRODUCTION

Toxic heavy metal contaminants have constituted serious global problem, presenting health risks to human beings, animals, and plants. Metals that pose these health risks are naturally occurring in nature but they become concentrated as a result of human industrial activities, and end up accumulating in elevated concentration in the environment (Xie et al., 2018; Huang et al., 2021).

Copper (Cu) is an essential micronutrient to plant which is utilised in numerous enzymatic processes and in the formation of chlorophyll and seed. Cu is one of eight vital plant micronutrients (Kaiser, 2018). Deficiency of Cu can lead to increased susceptibility to diseases such as ergot – which can cause significant loss of yield in small grains. It has also been reported by Kaiser (2018) that vegetable crops such as onions, lettuce and carrots are sensitive to copper deficiency. The amount of Cu available to plants

varies widely among soils. Copper in the soil held with clay minerals as cation and in association with organic matter. Some silicate minerals have been reported to contain Cu as filths. However, the deficiency of copper is more likely to occur in cereal grains, like wheat, barley and oat when grown on soil that are deficient in Cu.

Heavy metal contamination of the soil has been reported in many areas (UEPA, 2018). Irrational anthropogenic activities have impacted and resulted in the destruction of the ambient environment. Degradation of soil and water has resulted in build-up of contaminants in these spheres and further transfer of contaminants into the food chain (Sharma et al., 2021). Arable soil is frequently subjected to pollution with copper as the consequence of imbalanced fertilization with manure and organic fertilizers and/or extensive use of copper-containing fungicides (Ali et al., 2015).

As soon as Cu finds its way into soil and water, they can find their way into food chain, and the consumption of which could portend serious health implication to human (Huang et al., 2021). Although Cu is an essential element for human body, accumulation of high dose of this element may result in serious health challenges such as respiratory problem, gastrointestinal and growth retardation (Yamada et al., 2014; Kendall et al., 2015; Wu et al., 2016).

Soil pollution is a part of land degradation caused by the presence of human made chemicals mostly used for industrial activities, agricultural activities e.g. fertilizers, pesticides, herbicides, insecticides etc. and improper waste disposal or other alteration of the soil's natural environment. This form of pollution has a series of effects on the soil, plants and man which is a function of factors such as the type of pollutant, level of concentration of pollutant, level of absorption by the plants, and climatic conditions. In the soil, it affects the microbiota by changing the radical soil chemistry which makes the soil intolerable for the pre-existing organisms in the soil. In plants they alter the plant metabolism thus reducing crop yield (Ashraf et al., 2014).

It has been of increasing interest of the public to know the effect of polluted soils on plants. There are 2 sources of

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soil pollution by heavy metals namely: the natural source and artificial source (Wang et al., 2010), the natural source indicates that the trace metal concentration is derived from parent rocks and the anthropogenic source which indicates that the trace metal concentration originates from human activities e.g. mining, metal smelting, mineral fertilizers, waste water irrigation and exhaust emission (Takashi & Hidelaka, 2014).

Heavy metals are metallic chemicals which are not involved in plant metabolism and hence harms the plant when in a concentration higher than the required level in plants. Heavy metals are the main sources of soil pollution, heavy metals either in high or low concentration exhibits effects towards soil biota by affecting key metabolism and decreases the number and activities of the microbes resulting in a change in the population size, soil ecological diversity and overall activity of the soil microbiota. Heavy metals indirectly affect the actions of enzymes in the soil by shifting the microbial communities responsible for enzymes synthesis from their normal state (Ayten et al., 2011). Heavy metals also have its effects in plants, it is being introduced to the plants mostly from the soil alongside nutrients being absorbed by the root of the plants (Ayandiran et al., 2009).

Heavy metal accumulation in plants depends on the plant species and the efficiency of different plants absorption mechanism (Morin et al., 2007). The uptake and bioaccumulation of heavy metals in vegetables is influenced by many factors e.g. climate, atmospheric deposition of the heavy metal concentration of the heavy metal in the soil, the nature of the soil and the degree of maturity of the vegetable at the time of harvest. The consumption of heavy metals contaminated plants or foods can seriously deplete some essential nutrients in the body of humans which results into decrease in immunological disease, intrauterine growth retardation and higher prevalence of upper gastrointestinal cancer rates.

Most of the pollutants present in the plant's surrounding are accumulated by roots followed by leaves (Wang et al., 2007; Tripathi et al., 2020). Plants are equipped with the capability to carry out extraction, sequestration, and/ or degradation of environmental contaminants (Tripathi et al., 2020).

Apart from the potential health risks associated with consumption of vegetables such as *Celosia argentea* and *Amaranthus hybridus* reported by various researchers, Cruz et al. (2022) submitted that at toxic levels, Cu triggers physiological and biochemical disorders that reduces plant growth. The World Health Organization (WHO)/ Food and Agricultural Organization (FAO) recommended safe level for copper in vegetables and fruits is 40 mg/kg (Elbagermi et al., 2012). Accumulation of heavy metals in soils may give rise to decreased crop yield (Zhou et al., 2016; Chary et al., 2008), and bioavailability and bioaccumulation of these metals have been reported to be associated closely with adsorption and desorption of metals by and from certain soil constituents (Sparks, 2015). Therefore, the aim of this study is to evaluate the impact of copper pollution on the growth attributes of *Celosia argentea* and *Amaranthus hybridus*, and bioaccumulation of Cu in the plants.

MATERIALS AND METHODS

Study area

This study was carried out the University of Ilorin Botanical garden situated at coordinate 8°30' N and 50° E, Ilorin, Kwara State, Nigeria. The average annual rainfall of 800-1300 mm and a temperature range of 28 to 40 °C (Olawepo et al., 2022).

Experimental design: Seed material of both *Amaranthus hybridus* and *Celosia argentea* were procured at credible local seed vendors in Maraba, Ilorin. These seeds were initially planted and raised in the nursery for a period of 2 weeks before they were transplanted into experimental pots in a Screenhouse at the botanical garden. The pots were grouped into 2, one for *A. hybridus* and the other for *C. argentea*. The pots were filled with about 1.6 kg of loamy soil that were later amended with different concentrations of the Cu salt. These concentrations include 100 mg/kg soil (T_1), 200 mg/kg soil (T_2), 400 mg/kg soil (T_3), and the control without Cu contamination. Each of the various concentrations of Cu were replicated 3 times, and an additional 12 experimental pots were set aside for collection of data on the biomass of the 2 vegetables across the different concentrations.

Processing of the vegetables and determination of Cu concentration

Samples of the 2 vegetables were collected by harvesting the whole plant and they were washed thoroughly in clean water. This is to ensure they are free of sand and dirt. The samples were later rinsed briefly in distilled water. The samples were chopped into small pieces and air-dried at ambient temperature until fairly dry. They were then dried in the oven for 72 hours at 60 °C until constant weight is obtained (Ogunkunle et al., 2013). The resultant dry samples were pulverised in an electric blender and sieved through mesh (2 mm). Samples of *A. hybridus* and *C. argentea* (0.5 g) were weighed into crucible and ignited at 450–500 °C for a period of about 8 hours in muffle furnace, until a greyish-white ash was gotten. Five 5 ml of HNO_3 (2N) was added to each sample, which was subsequently filtered with a Whatman filter paper (No.540). The resulting filtrates were transferred into 100 ml graduated flask and made up with distilled water (Fadina et al., 2017). Nickel concentrations in the samples were determined using Atomic Absorption Spectrophotometer (AAS) (Buck Scientific Model 210 VPG) by following the operational procedure of Association of Chemist (AOAC, 2003; De Silva & Dayarathna, 2019).

RESULTS

Effect of different concentrations of Cu in polluted soil on growth attributes of *Amaranthus hybridus*

The stem length of *A. hybridus* treated with 200 mg/kg recorded the highest at 1, 2 and 3 WAT (3.98, 5.00 and 7.05 cm respectively), which was significantly different from the control plants that were grown in unpolluted soil except at 2WAT (3.00 cm). *Amaranthus hybridus* grown in soil contaminated with 400 mg/kg (T_3) gave the peak stem

Figure 1: Log-probit dosage curves obtained for (A) *Aedes albopictus* and (B) *Culex quinquefasciatus* larvae exposed to six different concentrations (250 ppm- 5 ppm) of garlic extract for 24 h, 48 h and 72 h

girth values at 1, 2 and 3 WAT (1.85, 1.89 and 1.97 cm respectively); however, the values were not significantly different from other treatments at $P<0.05$.

This observation shows that the Cu addition to the soil improved the most of the growth attributes of *A. hybridus* when the concentration is not greater than 200 mg/kg. Cu being an essential micronutrient to plants which helps to enhance chlorophyll formation and facilitate the activities of numerous enzymatic process which have culminated into the performance observed at concentration not higher than 200 mg/kg. This observation is in tandem with earlier report by Kaiser (2018) who submitted that elevated levels of Cu in the soil results in toxicity to plants. He remarked that Cu toxicity impair plant vigour, in addition to poor development of root system and seed germination.

Leaf traits of length and breadth were best in *stem* grown in 200 mg/kg of Cu polluted soil at 1, 2 and 3 WAT, though the

values were not significantly different from those recorded for other treatments ($P<0.05$). Similar result was obtained in the number of leaves, with significant differences ($P<0.05$) at 1, 2 and 3 WAT.

Similarly, Cruz et al. (2022) who worked on physiological and biochemical aspects of Cu toxicity in plants reported that high levels of Cu triggers physiological and biochemical disorders as exhibited by the decreased leaf area, root length, and SPAD index, and oxidative stress that damages cellular structures, DNA, proteins and lipids, in plant. This report agrees with the findings of this study as evidenced by the reduction in growth parameters at elevated level – when the Cu concentration was above 200 mg/kg. It may also be suggested that *A. hybridus* shows the capacity to tolerate high Cu concentration to a decent level given the growth parameter (stem girth) with highest value in soil contaminated with 400 mg/kg of Cu.

Table 1: Effect of different concentrations of Cu in polluted soil on growth attributes of *Amaranthus hybridus*.

Treatment	Stem length (cm)		
	1 WAT	2 WAT	3 WAT
Control	2.00±0.37 ^b	3.00±0.92 ^{ab}	3.67±1.05 ^b
T ₁	2.27±0.50 ^{ab}	2.77±0.64 ^b	3.70±1.09 ^b
T ₂	3.98±0.44 ^a	5.00±0.59 ^a	7.05±0.43 ^a
T ₃	2.58±0.31 ^{ab}	3.07±0.37 ^{ab}	3.80±0.39 ^b
P-value	0.013	0.094	0.018
Treatment	Stem girth (cm)		
	1 WAT	2 WAT	3 WAT
Control	1.55±0.21 ^a	1.86±0.22 ^a	1.93±0.23 ^a
T ₁	1.17±0.49 ^a	1.32±0.48 ^a	1.63±0.45 ^a
T ₂	1.63±0.29 ^a	1.73±0.29 ^a	1.81±0.30 ^a
T ₃	1.85±0.21 ^a	1.89±0.21 ^a	1.97±0.21 ^a
P-value	0.510	0.569	0.868
Treatment	Leaf length (cm)		
	1 WAT	2 WAT	3 WAT
Control	1.08±0.17 ^a	1.67±0.49 ^a	2.53±0.56 ^a
T ₁	1.10±0.16 ^a	1.83±0.39 ^a	2.88±0.70 ^a
T ₂	1.53±0.13 ^a	2.67±0.37 ^a	4.10±0.44 ^a
T ₃	1.07±0.17 ^a	1.55±0.30 ^a	2.53±0.50 ^a
P-value	0.145	0.211	0.179
Treatment	Leaf breadth (cm)		
	1 WAT	2 WAT	3 WAT
Control	0.70±0.26 ^a	0.88±0.28 ^a	1.28±0.33 ^a
T ₁	0.53±0.14 ^a	1.00±0.26 ^a	1.48±0.42 ^a
T ₂	1.27±0.33 ^a	1.43±0.15 ^a	2.20±0.20 ^a
T ₃	0.58±0.145 ^a	0.80±0.20 ^a	1.25±0.26 ^a
P-value	0.134	0.238	0.150
Treatment	Number of leaves		
	1 WAT	2 WAT	3 WAT
Control	4.50±0.34 ^b	6.17±0.84 ^{ab}	6.34±0.76 ^b
T ₁	4.34±0.56 ^b	5.17±0.75 ^b	6.67±1.05 ^b
T ₂	6.67±0.49 ^a	7.84±0.31 ^a	10.34±1.56 ^a
T ₃	5.17±0.48 ^b	6.50±0.85 ^{ab}	7.34±0.67 ^{ab}
P-value	0.009	0.010	0.060

Values (means ± standard error) with the same superscript letter(s) are significantly different at $P<0.05$.

WAT: Weeks After Planting

T₁: Soil treated with 100 mg/kg of Cu, T₂: Soil treated with 200 mg/kg of Cu, T₃: Soil treated with 400 mg/kg of Cu, and the Control without Cu contamination.

Effect of different concentrations of Cu in polluted soil on growth attributes of *Celosia argentea*

Celosia argentea grown in soil amended with 200 mg/kg of Cu salt gave the overall best performance from the assessment of the growth performance with peak values in leaf length and breadth, and number of leaves; however, those grown in soil amended with 100 mg/kg of Cu salt gave better result for stem length and girth, as shown in Table 2.

Stem length and girth values obtained at 1, 2 and 3 WAT were not significantly different across the treatments, however, *C. argentea* planted in soil contaminated with 100 mg/kg of Cu gave best record on both occasions. Least values at 3 WAT were obtained from those vegetables grown in soil polluted with 400 mg/kg of Cu (2.12 and 2.21 cm respectively). It is worthy to note that the control plant recorded the highest stem girth (2.94 cm) at WAT, even though it was not significantly different ($P < 0.05$).

Leaf length and breadth values recorded initially were not significantly different (1 WAT), but showed differences at 2 and 3 WAT. *Celosia argentea* grown on soil polluted with 200 mg/kg of Cu recorded highest values of leaf length and breadth at 3 WAT (4.63 and 2.27 cm) respectively. This reveals that the *C. argentea* grown in Cu polluted soil indicated positive impact on the growth parameters at concentrations of 200 mg/kg, which could be attributed to the optimal Cu requirement at that particular stage of growth and development.

This observation may also be attributed to the improved physiological processes occasioned by growing of *C. argentea* in soil amended with 100 and 200 mg/kg of Cu salt. The improved physiological process at these concentrations is evident by the higher values recorded for the aforementioned growth parameters.

This finding conforms to an earlier study by Odjegba & Bamgbose (2012) on toxicity assessment of treated effluents on *C. argentea*, reported that heavy metals pollutant were bioaccumulated in the vegetable, and resulted in 41% growth imbibition.

Comparable results were observed in number of leaves at 1, 2 and 3 WAT (4.67, 7.00 and 9.17); nevertheless, significant difference among the treatments was only observed at 3 WAT. This observation indicates that *C. argentea* has capability to tolerate high level of Cu concentration. This finding is in harmony with the report of a study by Wang et al. (2021), who analysed the physiological and metabolite response of *C. argentea* to copper stress. They suggested that *C. argentea* root strongly accumulate Cu^{2+} , which led to initiation of mechanisms such as higher electrolyte leakage, malondialdehyde, superoxide dismutase and peroxidase activity, resulting in higher ability to scavenge oxygen radicals and ensure the integrity of the cellular membrane. These mechanisms are geared at ensuring the plant deal with toxic levels of Cu through regulations to mitigate oxidative stress.

Assessment of the results of the bioaccumulation of Cu in *A. hybridus* indicated no significant difference ($P < 0.05$) across the treatments except the control where apparently

there was no contamination of the soil with Cu. However, the *A. hybridus* of T_1 treatment (100 mg/kg of Cu pollution) recorded the highest accumulation of Cu (73.77 mg/kg). This observation could be ascribed to higher accumulation rate of copper in the plant when grown in soil polluted with 100 mg/kg, as compared to those grown in contaminated soil with higher Cu concentration. It maybe that the absorption rate of Cu in *A. hybridus* and *C. argentea* is favoured at Cu concentration of 100 mg/kg, contrary to absorption rate at 200 and 400 mg/kg. The observation may also be ascribed to higher mobility rate of Cu at 100 mg/kg concentration. This finding is in tandem with the report of Adesanmi et al. (2019) who studied the bioaccumulation factor of selected heavy metals in *Zea Mays* and submitted that bioaccumulation factor (BAF) of Cu was lower than those recorded by Cd, Cr, and Pb, at high concentration of the heavy metal.

Similar bioaccumulation pattern was recorded in *C. argentea*, where the plants grown in soil polluted with 100 mg/kg of Cu recorded highest concentration of elemental Cu accumulation (73.77 mg/kg). Also, the values were not significantly different ($P < 0.05$) among the treatments except for the control where there was no contamination with Cu. This observation agrees with earlier report by Adu et al. (2022) who studied the comparative analysis of heavy metals concentration in soil and vegetable obtained from 2 sampling sites, submitted that the concentration of heavy metals in *C. argentea* organs were higher in samples collected from contaminated site, though there was bioaccumulation at farmland with low contamination. The finding of this study also conforms with the work of Ebabhi et al. (2020) who assessed the heavy metals in leafy vegetables from selected farms in Lagos State, and submitted that *C. argentea* bioaccumulate Cu even at low concentration, as was observed in samples of the vegetables obtained from farmlands that were not previously contaminated with Cu.

Wet and dry weights of *Amaranthus hybridus* and *Celosia argentea* grown on Copper polluted soil

There was no significant difference in the wet and dry weight values across the treatments ($P < 0.05$). The highest and lowest wet weight values were recorded in *A. hybridus* planted in soil polluted with 200 and 400 mg/kg (1.46 and 0.47 g) respectively. However, assessment of the *A. hybridus* dry weights shows that those cultivated in soil contaminated with 100 mg/kg of copper recorded highest dry weight value (0.24 g). *Celosia argentea* did not show significant difference across the treatments ($P < 0.05$) for wet and dry weight parameters. Nonetheless, the *C. argentea* grown in soil polluted with 200 mg/kg of Cu recorded the highest wet and dry weights (1.62 and 0.34 g) respectively. This observation could be ascribed to deleterious impact of the Cu contaminant at elevated levels of 400 mg/kg, which may give rise to metabolic distortion of the vegetable resulting in low biomass accumulation. Cruz et al. (2022) opined that despite the fact that Cu is an essential micronutrient in plants, at toxic levels it leads to reduction in plant growth due to physiological and biochemical disorder. This also agrees with the finding of Ade-Ademilua

Table 2: Effect of different concentrations of soil Cu pollution on the growth of *Celosia argentea*.

Treatment	Stem length (cm)		
	1 WAT	2 WAT	3 WAT
Control	1.60±0.37 ^a	1.95±0.37 ^a	2.38±0.39 ^a
T ₁	2.07±0.20 ^a	2.24±0.20 ^a	2.48±0.15 ^a
T ₂	1.45±0.08 ^a	1.67±0.12 ^a	2.37±0.30 ^a
T ₃	1.50±0.30 ^a	1.64±0.31 ^a	2.12±0.69 ^a
P-value	0.350	0.381	0.940
Treatment	Stem girth (cm)		
	1 WAT	2 WAT	3 WAT
Control	2.10±0.25 ^a	2.37±0.22 ^a	2.94±0.15 ^a
T ₁	2.69±0.25 ^a	2.70±0.23 ^a	2.77±0.23 ^a
T ₂	2.50±0.18 ^a	2.52±0.30 ^a	2.81±0.40 ^a
T ₃	2.27±0.52 ^a	2.42±0.52 ^a	2.41±0.51 ^a
P-value	0.607	0.904	0.744
Treatment	Leaf length (cm)		
	1 WAT	2 WAT	3 WAT
Control	1.82±0.36 ^a	2.60±0.28 ^{ab}	3.10±0.64 ^{ab}
T ₁	1.98±0.11 ^a	2.68±0.23 ^{ab}	3.47±0.28 ^{ab}
T ₂	2.05±0.30 ^a	3.48±0.25 ^a	4.63±0.42 ^a
T ₃	1.28±0.30 ^a	2.50±0.55 ^b	2.42±0.66 ^b
P-value	0.243	0.064	0.050
Treatment	Leaf breadth (cm)		
	1 WAT	2 WAT	3 WAT
Control	0.88±0.21 ^a	1.44±0.14 ^a	1.60±0.33 ^{ab}
T ₁	1.00±0.19 ^a	1.58±0.14 ^a	1.92±0.28 ^{ab}
T ₂	0.90±0.82 ^a	1.68±0.09 ^a	2.27±0.14 ^a
T ₃	0.71±0.19 ^a	0.89±0.20 ^b	1.11±0.27 ^b
P-value	0.689	0.005	0.027
Treatment	Number of leaves		
	1 WAT	2 WAT	3 WAT
Control	4.20±0.49 ^a	5.40±0.60 ^a	7.20±1.16 ^{ab}
T ₁	4.17±0.17 ^a	6.50±0.34 ^a	7.50±0.34 ^{ab}
T ₂	4.67±0.21 ^a	7.00±0.58 ^a	9.17±0.70 ^a
T ₃	3.86±0.51 ^a	5.43±0.87 ^a	5.71±1.25 ^b

Values (means ± standard error) with the same superscript letter(s) are significantly different at P<0.05.

WAT: Weeks After Planting

T₁: Soil treated with 100 mg/kg of Cu, T₂: Soil treated with 200 mg/kg of Cu, T₃: Soil treated with 400 mg/kg of Cu, and the Control without Cu contamination.

Table 3: Elemental copper concentration in *Amaranthus hybridus* and *Celosia argentea* grown in nickel polluted soil.

Treatment	Copper conc. in <i>A. hybridus</i> (mg/kg)	Copper conc. in <i>C. argentea</i> (mg/kg)
Control	34.17±3.02 ^b	37.40±3.31 ^b
T ₁	73.77±6.74 ^a	74.87±6.89 ^a
T ₂	53.07±1.24 ^{ab}	53.07±13.11 ^{ab}
T ₃	55.57±8.55 ^{ab}	66.54±9.64 ^{ab}
P-value	0.077	0.039

Values (means ± standard error) with the same superscript letter(s) are significantly different at P<0.05.

WAT: Weeks After Planting

T₁: Soil treated with 100 mg/kg of Cu, T₂: Soil treated with 200 mg/kg of Cu, T₃: Soil treated with 400 mg/kg of Cu, and the Control without Cu contamination.

& Obalola (2008) that *C. argentea* recorded a reduced dry matter when the pollutant heavy metal bioaccumulated was high. They investigated the effect of cement dust pollution

on *C. argentea* and concluded that the significant decrease in vegetative growth of polluted plants may be attributed to decline in photosynthetic activities of the polluted plant.

Table 4: Wet and dry weights of *Amaranthus hybridus* and *Celosia argentea* grown on Copper polluted soil at one week after planting (WAT).

Treatment	A. hybridus		C. argentea	
	Wet weight (g)	Dry weight (g)	Wet weight (g)	Dry weight (g)
Control	0.65±0.40 ^a	0.10±0.06 ^a	1.25±1.87 ^a	0.20±0.06 ^a
T ₁	0.75±0.40 ^a	0.24±0.13 ^a	1.15±0.18 ^a	0.14±0.02 ^a
T ₂	1.46±0.17 ^a	0.17±0.06 ^a	1.62±0.31 ^a	0.34±0.07 ^a
T ₃	0.47±0.26 ^a	0.13±0.09 ^a	1.03±0.69 ^a	0.14±0.08 ^a
P-value	0.736	0.222	0.144	0.754

Values (means ± standard error) with the same superscript letter(s) are significantly different at P<0.05.

WAT: Weeks After Planting

T₁: Soil treated with 100 mg/kg of Cu, T₂: Soil treated with 200 mg/kg of Cu, T₃: Soil treated with 400 mg/kg of Cu, and the Control without Cu contamination.

CONCLUSIONS

Amaranthus hybridus expressed good performance when grown in soil pretreated with 200 mg/kg of Cu, with resultant significantly (P<0.05) high values recorded in the growth parameters examined such as stem length, leaf length and breadth and number of leaves. The assessment of the growth attributes of *C. argentea* indicated good performance when planted in soil amended with 100 mg/kg of Cu. The study revealed that Cu resulted in retarded growth indices in *C. argentea* when grown in soil with Cu concentration higher than 100 mg/kg. *Amaranthus hybridus* and *Celosia argentea* both bioaccumulated more Cu at 100 mg/kg; and the highest wet and dry weights for both vegetables were recorded at 200 mg/kg, though without significant difference (P<0.05).

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CONFLICT OF INTEREST

The authors hereby declare that there is no conflict of interest among the authors regarding the publication of this article.

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