COPPER POLLUTION EFFECTS ON GROWTH AND BIOMASS YIELD OF NIGERIAN VEGETABLES

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ABSTRACT

This study investigated the impact of copper pollution on the biomass and dry matter of two commonly consumed vegetables in Nigeria, *Amaranthus hybridus* (Efo tete) and *Celosia argentea* (Efo soko). The plants were grown in soil treated with different concentrations of copper (100 mg/kg, 200 mg/kg, and 400 mg/kg) and in unpolluted soil for comparison. The results showed that both vegetables absorbed copper from the soil, but the levels were within the permissible limit (5-100 mg/kg). Interestingly, the copper absorption did not affect the biomass or dry matter of the plants. These findings suggest that these vegetables are tolerant to copper pollution and could be cultivated in contaminated soils without affecting their nutritional value.

Keywords: copper pollution, permissible limit, *Amaranthus hybridus, Celosia argentea*

INTRODUCTION

Pollution refers to the process or action of contaminating and making various elements of the environment, such as land, air, and water, dirty and unsafe for use. It occurs when contaminants, both in tangible and intangible forms, are introduced into the natural environment. These contaminants, also known as pollutants, can range from simple factors like noise, light, sound, and temperature to more complex substances that ultimately pollute the environment.

In 2015, pollution was responsible for the deaths of approximately 9 million people worldwide, with about one in every six premature deaths being linked to pollution (Laura, 2017). According to Alina Bradford in 2018, Pure Health, a non-profit organization, reported that over 200 million people worldwide are affected by toxic pollution. In areas severely affected by pollution, babies are born with defects, IQ points are reduced by 30-40, and life expectancy drops to 45 years due to diseases like cancer, among others.

There are two main sources of pollution. The first is point source pollution, where the origin of the pollutants can be traced back to a specific source. The second is non-point source pollution, which is more difficult to attribute to a single source and is often referred to as diffuse pollution.

Pollution takes three primary forms: air pollution (contamination of the atmosphere), land/soil pollution (degradation of land caused by misuse), and water pollution (contamination of any water body). Additionally, other forms of pollution include light pollution (which brightens the night sky and hinders visibility of stars and planets due to improper lighting in communities), thermal pollution (an increase in environmental temperature caused by human activities), radioactive pollution (the release of radioactive substances or high-energy particles into the air, water, or earth due to human activity, either accidental or intentional), and noise pollution (when sound produced by a source exceeds the acceptable levels).

Soil pollution is a form of land degradation caused by the presence of human-made chemicals, primarily resulting from industrial and agricultural activities. These chemicals include fertilizers, pesticides, herbicides, insecticides, and improper waste disposal, among other factors that disrupt the natural environment of the soil. The effects of soil pollution on the soil itself, plants, and humans depend on the type and concentration of pollutants, the absorption capacity of plants, and the prevailing climatic conditions.

In the soil, pollution affects the microbiota by altering the chemical composition of the soil, rendering it inhospitable for the existing organisms. For plants, pollutants disrupt their metabolism, leading to reduced crop yields. The impact of polluted soils on plants has garnered increasing attention from the public.

Soil pollution from heavy metals can have two sources: natural and artificial. The natural source refers to trace metal concentrations derived from parent rocks, while the anthropogenic source originates from human activities such as mining, metal smelting, mineral fertilizers, wastewater irrigation, and exhaust emissions. Heavy metals are metallic chemicals that are not involved in plant metabolism and can harm plants when present in concentrations exceeding the required levels.

Heavy metals are the primary contributors to soil pollution. High or low concentrations of heavy metals can affect soil biota by disrupting key metabolic processes, reducing microbial populations and activity, and altering soil ecological diversity. Heavy metals indirectly influence enzyme actions in the soil by altering the microbial communities responsible for enzyme synthesis.

Heavy metals also affect plants as they are absorbed by the roots along with essential nutrients from the soil. The accumulation of heavy metals in plants depends on the plant species and their efficiency in absorbing different metals. Factors such as climate, atmospheric deposition, soil concentration of heavy metals, soil characteristics, and the maturity of vegetables at the time of harvest influence the uptake and bioaccumulation of heavy metals in vegetables.

Consuming plants or foods contaminated with heavy metals can deplete essential nutrients in the human body, leading to immunological disorders, intrauterine growth retardation, and a higher prevalence of upper gastrointestinal cancer.

Copper is a reddish-orange metal with high thermal and electrical conductivity. It is used as a conductor, building material, and in alloys like sterling silver and cupronickel. It occurs naturally in various minerals. Copper, ranking 6th in abundance among heavy metals like Pb, Cr, and Zn, is primarily responsible for pollution due to human activities such as copper mining, smelting, fossil fuel combustion (especially coal), copper plumbing, and fertilizer use. Copper pollution affects the natural environment, including air, water, and land habitats.

The experiment conducted by Adrees *et al*. (2015) reported that Copper pollution reduces the biomass of plants. Shoeran *et al*. (2011) reported that the permissible limit of Copper in plants ranges from 5-100 mg/kg (Adriano 2001). Lucia *et al.* (2010) reported that Copper salt accumulates in the plants but has no effect on the dry matter. Ogunkunle *et al*. (2013) reported that of the two vegetables: *Lycopersicon esculentum* and *Amaranthus hybridus*, *Lycopersicon esculentum* had the highest absorbed Copper content as compared to *Amaranthus hybridus*.

Existing literature on experimental pollution has focused on studying different chemical pollutants individually, such as Pb, Cu, Zn, Cr, without considering the relationship between soil pollutant concentration and plant absorption. Some studies neglected this factor and conducted experiments using plants collected from roadside areas, while others used high pollutant levels, leading to residual soil contamination and potential contamination of non-polluted soil when disposing of the polluted soil. This study aims to address these gaps by focusing on a specific chemical pollutant, considering absorption-concentration factors, and using lower pollutant concentrations.

Soil pollution is a growing concern due to increasing human activities that introduce pollutants into the soil. This pollution not only affects the soil itself but also impacts the plants grown in contaminated soil and the individuals who consume those plants. Reports indicate a significant number of deaths caused by living or working in polluted areas, emphasizing the need to understand the causes and effects of pollution, the impact of pollutant concentration levels, and the detrimental effects on both plant health and human well-being. Therefore, this study was conducted to assess the effects of copper on the growth, biomass yield, and copper accumulation in *Amaranthus hybridus* and *Celosia argentea*.

MATERIALS AND METHODS

Description of experimental site

The experiment was carried out in the Biological Garden of the University of Ilorin, Ilorin, Nigeria (8’30 ^{o}N and 50 ^{o}E). The study site is situated in the southern guinea savannah belt of Nigeria with an annual rainfall of between 800-1300 mm and temperature of between 28°C and 40°C. The average morning relative humidity of Ilorin is 70% which falls to 45% in the afternoon.

Experimental set-up

Seed of *Amaranthus hybridus* and *Celosia argentea* were purchased from an agrochemical shop in Ilorin. The seeds were raised for two weeks and later transplanting into experimental pots.

Two sets of experimental pots were prepared. One for *Amaranthus hybridus* and the other for *Celosia argentea*. A set consists of 1.6 kg of loamy soil packed into plastic pots and polluted with varying concentration of copper. The concentrations used were 100 mg/kg soil (C1), 200 mg/kg soil (C2), 400 mg/kg soil (C3) and control (C0) without copper pollution with each treatment replicated trice. A total of 12 pots set up for *Amaranthus hybrius* and *Celosia argentea* respectively. The treatment and replicates were arranged in a complete block design.

Data collection

Data were collected on stem length, stem girth, number of leaves, leaf length and leaf breath following one week after transplanting (1WAT) for three weeks. Stem length was measured using meter rule, leaf length and leaf breath were also measured using the meter rule, stem girth was measured using Vernier caliper and the numbers of leaves were counted by visual observation. At 4 weeks after transplanting (4WAT), the plants were uprooted, weighed fresh and dried to a constant weight. The plants samples were then digested using Aqua regia method. To the grounded sample in the sample bottles, concentrated HCL and concentrated HNO_3 in the ratio 3:1 were added. This solution was heated and allowed to cool. After cooling, the solution was filtered. The empty sample bottles were washed with distilled water and filtrate was introduced into the sample bottles and analyzed by Atomic Absorption Spectrophotometry.

Data analysis

The data collected were compared using ANOVA and the means were by DMRT using SPSS.

RESULTS

Stem length.

The stem length for *Amaranthus hybridus* was significantly different at 1WAT, 2WAT and 3WAT (p= 0.013, 0.094 and 0.018 respectively). At 1WAT, C2 had the highest stem length while C0 had the least. The stem length at 2WAT varied significant (p=0.094) among the treatment for *Amaranthus hybridus*; C2 had the highest stem length while C1 had the least at 2WAT. At 3WAT, C2 had the highest stem length while C0 had the least (Table 1).

Stem girth.

The stem girth for *Amaranthus hybridus* was not significantly different in all the treatments. The p-values were greater than 0.05: p-values =0.510. 0.569 and 0.868 for 1WAT, 2WAT and 3 WAT respectively, which shows that there was no significant difference in the treatment for all the weeks (Table 2).

Table 1: Effect of copper on stem length of *Amaranthus hybridus* grown in a copper polluted soil.

Treatment	1WAT	2WAT	3WAT
C0	2.00 ± 0.37^{b}	3.00 ± 0.92^{ab}	3.67 ± 1.05^{b}
C1	2.27 ± 0.50^{ab}	2.77 ± 0.64^{b}	3.70 ± 1.09^{b}
C2	3.98 ± 0.44^{a}	5.00 ± 0.59^{a}	7.05 ± 0.43^{a}

C3	2.58±0.31[ab]	3.07±0.37[ab]	3.80±0.39[b]
p-value	0.013	0.094	0.018

Values (mean ± standard error of mean) with the same superscript are not significant different at p>0.05. WAT: Weeks after planting

Table 2: Effect of copper on stem girth of *Amaranthus hybridus* grown in a copper polluted soil.

Treatment	1WAT	2WAT	3WAT
C0	1.55±0.21[a]	1.86±0.22[a]	1.93±0.23[a]
C1	1.17±0.49[a]	1.32±0.48[a]	1.63±0.45[a]
C2	1.63±0.29[a]	1.73±0.29[a]	1.81±0.30[a]
C3	1.85±0.21[a]	1.89±0.21[a]	1.97±0.21[a]
P-value	0.510	0.569	0.868

Values (mean ± standard error of mean) with the same superscript are not significant different at p>0.05.

Leaf length.

The leaf length of *Amaranthus hybridus* was not significantly different in all treatments, the p-values were greater than 0.05: p-value= 0.145, 0.211 and 0.179 for 1WAT, 2WAT and 3WAT respectively (Table 3).

Leaf breadth.

Leaf breadth of *Amaranthus hybridus* showed no significant difference in all the treatments, p-values were greater than 0.05, p-values are 0.134, 0.238 and 0.150 for 1WAT, 2WAT and 3WAT respectively (Table 4).

Table 3: Effect of copper on Leaf length of *Amaranthus hybridus* grown in a copper polluted soil.

Treatment	1WAT	2WAT	3WAT
C0	1.08±0.17[a]	1.67±0.49[a]	2.53±0.56[a]
C1	1.10±0.16[a]	1.83±0.39[a]	2.88±0.70[a]
C2	1.53±0.13[a]	2.67±0.37[a]	4.10±0.44[a]
C3	1.07±0.17[a]	1.55±0.30[a]	2.53±0.50[a]
p-value	0.145	0.211	0.179

Values (mean ± standard error of mean) with the same superscript are not significant different at p>0.05.

Table 4: Effect of copper on Leaf breadth of *Amaranthus hybridus* grown in a copper polluted soil.

Treatment	1WAT	2WAT	3WAT
C0	0.70±0.26[a]	0.88±0.28[a]	1.28±0.33[a]

C1	0.53±0.14[a]	1.00±0.26[a]	1.48±0.42[a]
C2	1.27±0.33[a]	1.43±0.15[a]	2.20±0.20[a]
C3	0.58±0.145[a]	0.80±0.20[a]	1.25±0.26[a]
p-value	0.134	0.238	0.150

Values (mean ± standard error of mean) with the same superscript are not significant different at p>0.05.

Number of leaves.

The number of leaves of *Amaranthus hybridus* was significantly different for 1WAT and 2WAT, p-values = 0.009 and 0.010 respectively. C2 had the highest number of leaves for both weeks, while C1 had the least. However, there was no significant difference for 3WAT, P-value 0.060 (Table 5).

Table 5: Effect of copper on Number of leaves of *Amaranthus hybridus* grown in a copper polluted soil

Treatment	1WAT	2WAT	3WAT
C0	4.50±0.34[b]	6.17±0.84[ab]	6.34±0.76[b]
C1	4.34±0.56[b]	5.17±0.75[b]	6.67±1.05[b]
C2	6.67±0.49[a]	7.84±0.31[a]	10.34±1.56[a]
C3	5.17±0.48[b]	6.50±0.85[ab]	7.34±0.67[ab]
P-value	0.009	0.010	0.060

Values (mean ± standard error of mean) with the same superscript are not significant different at p>0.05.

Stem length.

The stem length of *Celosia argentea* was not significantly different for all treatments. P-values were greater than 0.05, P-value= 0.350, 0.381 and 0.940 for 1WAT. 2WAT and 3WAT respectively (Table 6).

Stem girth.

The stem girth for *Celosia argentea* showed no significant difference in all the treatments, P-values = 0.607, 0.903 and 0.744 for 1WAT, 2WAT and 3WAT respectively (Table 7).

Table 6: Effect of copper on Stem length of *Celosia argentea* grown in copper polluted soils.

Treatment	1WAT	2WAT	3WAT
C0	1.60±0.37[a]	1.95±0.37[a]	2.38±0.39[a]
C1	2.07±0.20[a]	2.24±0.20[a]	2.48±0.15[a]

C2	1.45±0.08[a]	1.67±0.12[a]	2.37±0.30[a]
C3	1.50±0.30[a]	1.64±0.31[a]	2.12±0.69[a]
P-value	0.350	0.381	0.940

Values (mean ± standard error of mean) with the same superscript are not significant different at p>0.05.

Table 7: Effect of copper on Stem girth of *Celosia argentea* grown in copper polluted soils.

Treatment	1WAT	2WAT	3WAT
C0	2.10±0.25[a]	2.37±0.22[a]	2.94±0.15[a]
C1	2.69±0.25[a]	2.70±0.23[a]	2.77±0.23[a]
C2	2.50±0.18[a]	2.52±0.30[a]	2.81±0.40[a]
C3	2.27±0.52[a]	2.42±0.52[a]	2.41±0.51[a]
P-value	0.607	0.904	0.744

Values (mean ± standard error of mean) with the same superscript are not significant different at p>0.05.

Leaf length.

The leaf length for *Celosia argentea* was not significantly different in all the treatments, P-value was 0.243, 0.064 and 0.050 for 1WAT, 2WAT and 3WAT respectively (Table 8).

Leaf breadth.

The leaf breadth of *Celosia argentea* was not significantly different in 1WAT, P-value were 0.689. However, for 2WAT and 3WAT there was significant difference in the leaf breadth, P-values were 0.005 and 0.027 (Table 9).

Table 8: Effect of copper on Leaf length of *Celosia argentea* grown in copper polluted soils.

Treatment	1WAT	2WAT	3WAT
C0	1.82±0.36[a]	2.60±0.28[ab]	3.10±0.64[ab]
C1	1.98±0.11[a]	2.68±0.23[ab]	3.47±0.28[ab]
C2	2.05±0.30[a]	3.48±0.25[a]	4.63±0.42[a]
C3	1.28±0.30[a]	2.50±0.55[b]	2.42±0.66[b]
P-value	0.243	0.064	0.050

Values (mean ± standard error of mean) with the same superscript are not significant different at p>0.05.

Table 9: Effect of copper on Leaf breadth of *Celosia argentea* grown in copper polluted soils.

Treatment	1WAT	2WAT	3WAT
C0	0.88±0.21[a]	1.44±0.14[a]	1.60±0.33[ab]
C1	1.00±0.19[a]	1.58±0.14[a]	1.92±0.28[ab]
C2	0.90±0.82[a]	1.68±0.09[a]	2.27±0.14[a]

C3	0.71±0.19[a]	0.89±0.20[b]	1.11±0.27[b]
P-value	0.689	0.005	0.027

Values (mean ± standard error of mean) with the same superscript are not significant different at p>0.05.

Number of leaves.

The number of leaves for *Celosia argentea* showed no significant difference for all the treatments, P-values were 0.509, 0.258 and 0.104 for 1WAT. 2WAT and WAT respectively (Table 10).

Table 10: Effect of copper on Number of leaves of *Celosia argentea* grown in copper polluted soil.

Treatment	1WAT	2WAT	3WAT
C0	4.20±0.49[a]	5.40±0.60[a]	7.20±1.16[ab]
C1	4.17±0.17[a]	6.50±0.34[a]	7.50+0.34[ab]
C2	4.67±0.21[a]	7.00±0.58[a]	9.17±0.70[a]
C3	3.86±0.51[a]	5.43±0.87[a]	5.71±1.25[b]
P-value	0.509	0.258	0.104

Values (mean ± standard error of mean) with the same superscript are not significant different at p>0.05.

Concentrations of copper in *Amaranthus hybridus* and *Celosia argentea*.

For *Celosia argentea*, there was significant difference among the treatments and control i.e. P < 0.05, C1 had the highest mean value of 74.87. C3 had the mean value of 66.54. C2 had the mean value of 53.07. The control has its mean value to be 37.40. For *Amaranthus hybridus*, there was no significant difference among the treatments and control except for C1 at P> 0.05 (Figure1).

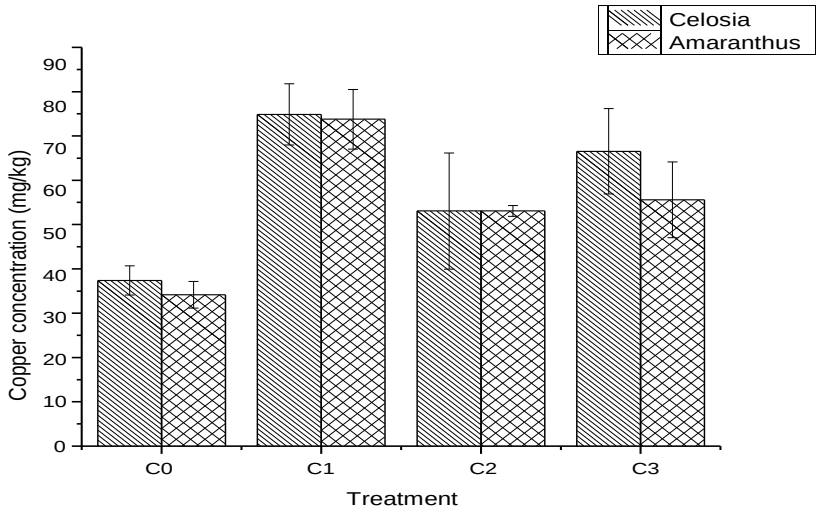


Figure 1: Copper concentration (mg/kg) in *Celosia argentea* and *Amarathus hybridus* grown in copper polluted soil.

Dry and wet weights of *Amaranthus hybridus*.

There was no significant difference in dry weight and wet weight among the treatments and control at P > 0.05 (Figure2).

Dry and wet weights of *Celosia argentea*.

There was no significant difference in dry weight and wet weight among the treatments and control i.e. P> 0.05 (Figure 3).

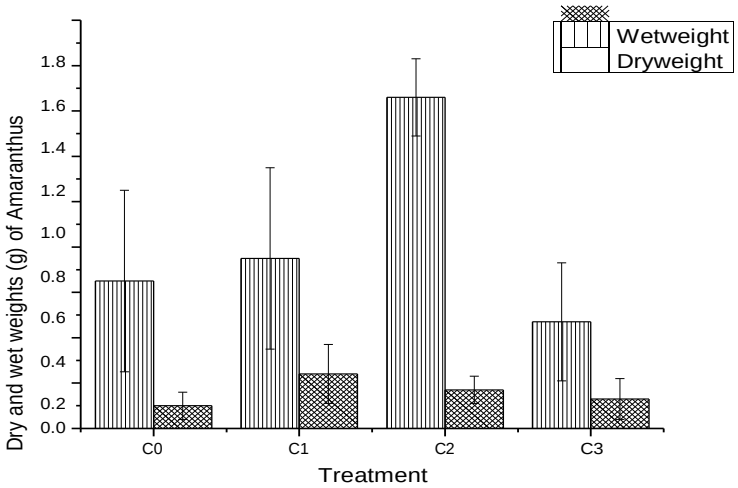


Figure 2: Dry weight and wet weights of *Amaranthus hybridus* grown in copper polluted soil.

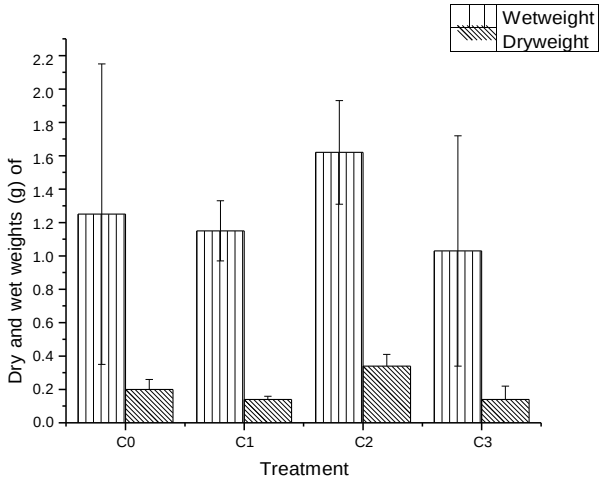


Figure 3: Dry weight and wet weights of *Celosia argentea* grown in copper polluted soil.

DISCUSSION

The study examined the impact of increasing copper pollutant concentration on the biomass and absorption levels in two vegetable species, *Amaranthus hybridus* and *Celosia argentea*. Surprisingly, the results revealed that the concentration of the pollutant did not have a consistent effect on the biomass of either vegetable. The expected trend of increased biomass with higher copper concentrations was not observed. Specifically, the growth parameters such as stem

length, stem girth, leaf length, leaf breadth, and number of leaves did not follow the anticipated pattern. If copper concentration had a positive effect on growth, the trend would have been C3 > C2 > C1. However, for *Amaranthus hybridus*, the trend was C2 > C1 > C3, and for *Celosia argentea*, it was C2 > C1 > C3.

Furthermore, the dry weight of the vegetables was not significantly affected by the copper concentration, including the highest level (C3) and the control. These findings align with a previous report by Lucia *et al*. (2010), indicating that the dry weight of the vegetables remains unaffected by copper concentration.

The study provided data on copper concentration levels in the different treatments and the control for both *Celosia argentea* and *Amaranthus hybridus*. Notably, these concentrations were found to be below the permissible limits of copper in plants according to Shoeran *et al.* (2011).

Interestingly, increasing the copper concentration did not lead to a corresponding increase in the absorbed concentration of the pollutant in the vegetables. The observed pattern did not follow the expected sequence based on increasing concentration levels. For *Celosia argentea*, the first treatment (C1) had the highest mean absorbed concentration, followed by C3 and then C2. Similarly, for *Amaranthus hybridus*, the first treatment (C4) had the highest mean absorbed concentration, followed by the third treatment (C3), and finally C2. This contradicts the assumption that absorption levels would directly correlate with increasing pollutant concentration.

Additionally, there was variation in the concentration of the pollutant absorbed by the two vegetable species. *Celosia argentea* demonstrated a higher mean absorbed concentration compared to *Amaranthus hybridus*. This indicates that *Amaranthus hybridus* may either be more tolerant to the pollutant or absorb it at a slower rate, consistent with the findings of Ogunkunle *et al.* (2013).

CONCLUSION

The study's results indicate that increasing copper pollutant concentration did not consistently affect the biomass or absorbed concentration in the examined vegetable species.

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