# Compost application, residual toxicity, heavy metal contamination, and associated potential health risk in leafy vegetable production in Northern Region of Ghana

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The addition of manure, and compost to the soil can improve soil structure, water holding capacity, and nutrient retention, all of which support long term carbon storage, improve crop productivity and quality, and play a pivotal role in climate-resilient regenerative sustainable agricultural system. Compost, by contributing humified carbon, can build passive Soil Organic Carbon pool as compared to fresh residues or raw manure. However, compost produced from industrial effluents, municipal waste and other sources may induce to potential health risk, residual toxicity and heavy metal contamination in fresh or processed produce. This chapter highlights the effect of compost application in leafy vegetable production in Northern region of Ghana and the potential health risk associated with the practice. The chapter delves into the effect of compost application and subsequent potential health risk associated through the outcome of an experiment conducted in the upland research field of the CSIR – SARI located near Nyankpala in the Northern Region of Ghana.

***Keywords:*** *Compost, bioavailability, amendments, potential health Risk, MRL, ACARP, DeCo*

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To elucidate the basic essence of the chapter, an on-station experiment was set up to assess the impact of certain commercial composts (ACARP and DeCo) as well as chicken manure (CM) on the levels of heavy metals in the leaves of roselle (*Hibiscus sabdariffa* L.) and jute mallow (*Corchorus olitorius*), which are commonly used as green vegetables and subsequently to evaluate the health risks linked to consuming these leafy vegetables grown with these soil amendments applied @ 10 t/ ha. The experimental design employed was a randomized complete block design (RCBD) with four replications. The levels of cadmium (Cd) and lead (Pb) found in the processed leaves of roselle were (0.8 mg/kg) and (5.0 mg/kg), respectively. Cadmium and lead are present in CM, ACARP, and DeCo composts in addition to necessary elements like zinc and copper. Applying these composts to the production of roselle and jute mallow may result in heavy metal residues at concentrations higher than international standards, which could be harmful to consumer's health. So, it is high time for concerted research for consideration while applying compost in crop production to minimize residual toxicity of heavy metals, harmful toxicant and other associated potential health hazards.

**Introduction**

Vegetable production in Ghana is usually carried out in backyard gardens, market gardens and truck farms delivering fresh produce to urban, semi-urban and peri-urban communities, and even for export. According to Kamran et al. (2013) however, many of the soils in which these vegetable crops are cultivated have been found to contain potentially toxic elements. This is because, these vegetable production sites are usually sited close to motorable roads and busy streets, where the vegetable crops are exposed to vehicular emissions (Drechsel and Keraita, 2014). Moreover, vegetable crops produced from these sites are most frequently watered with sewage, which typically contains high levels of heavy metals and infectious microorganisms. Such vegetable crops are also commonly fertilized with cow dung, sheep droppings, goat droppings, pig droppings, sewage sludge, and poultry droppings. This production system is made worse with the abusive use of pesticides, herbicides, and in some cases fungicides; all of which may result in the bioaccumulation of potentially toxic elements in the production environment (IWMI, 2008).

Heavy metals are naturally present in the earth and become a component of the soil's constituents during the weathering process (Kabata-Pendias, 2011). Their concentrations vary according to the parent material and may rise as a result of certain industrial practices, such as the use of specific inorganic and organic fertilizers in crop production that are bioavailable to plants and may contain heavy metals (Chaney, 2012). Based on research done by Delgado Arroyo et al. (2014); Chastain et al., Agriculture and Agri-food Canada (1990). (n). (d). In addition to plant nutrients, poultry manure contains heavy metals such as arsenic (As), lead (Pb), cadmium (Cd), zinc (Zn), copper (Cu), and nickel (Ni). Ghaly & Alkoaik (2010) also discovered that Zn and Cu are present in the organic fraction of municipal solid waste at 211.0 mg/kg. Ayari et al (2010) published a related report which found that 337 mg/kg of Cu were present in municipal solid waste compost.

Emissions from fossil fuel-powered vehicles are another activity that adds to the buildup of heavy metals in the environment. According to Popescu (2011), vehicle emissions release heavy metals like Pb and Cd, which are then released into the atmosphere, washed into the soil by rainwater, and absorbed by plants into their edible parts, which are then consumed by humans. It is well known that vegetables, particularly the leafy ones, accumulate a lot of these heavy metals (Puschenreiter et al. 2005) and presents a significant risk to human health due to their increased consumption. In order to determine whether edible plant parts contain heavy metals, Wamalwa et al. (2015) collected samples of leafy vegetables in an urban area to check for heavy metals; the findings indicated that Pb levels were higher than the MRLs.

According to Martin and Griswold (2009) and Karman et al (2013), heavy metal residues build up in the body's essential organs. Risk is a function of the probability of the occurrence of an adverse health effect. In a study by Khan et al. (2008), it is mentioned that, the accumulation of heavy metal in soils and its translocation into plants is of great concern because of the potential health risks they pose to humans.

Various strategies that has been explored and can be adopted to mitigate heavy metal pollution in the environment (soil and air) include bioremediation which involves the use of living organisms to remove heavy metals from the environment. Because it is a natural process of cleaning the soil in particular, it is a widely acceptable method (Sarma, 2011). Bioremediation encompasses rhizofiltration (Yadav et al., 2011; Krishna et al., 2012)., phytostabilization (Soudek et al., 2012), phytovolatilization, and phytoextraction Agricultural waste materials such as biochar is also being exploited for its potential in the management of heavy metal polluted soils (Chibuike & Obiora, 2014).

Therefore, the purpose of this study was to ascertain how certain commercially used composts and chicken manure affected the bioavailability of Cd, Pb, Zn, and Cu in roselle (*Hibiscus sabdariffa* L.) and jute mallow (*Corchorus olitorius*) leaves used as green vegetables.

## Materials and methods

### Description of experimental site

The study was conducted at the upland field of the Council for Scientific and Industrial Research – Savanna Agricultural Research Institute (CSIR-SARI), Nyankpala, in the Tolon District of the Northern Region of Ghana. The experimental site is situated in a vicinity of 200 m from the main Tamale – Nyankpala road where vehicular activity on the road is brisk on daily basis. The experimental site has been under continuous agriculture activities with the application of various agro-inputs (fertilizers, pesticides and weedicides) for several years. The upland field (Latitude 09$^{o}$ 25" N, Longitude 00$^{o}$ 58" W) with an altitude of 183 m above sea level is about 200 m west of the Changnaayili village.

The soils found in the experimental site have been described as *Ferric luvisols* (FAO-UNESCO, 2002). They are reported to have been formed from ground water laterite soil with concretions and are classified into: (a) Kpalsawgu series which are imperfectly drained, and occurs within the east on the low-lying uplands and (b) Changnayili series which are poorly drained, and occupies the lower slopes and the valley bottoms. They are both sandy loam soils that are slightly acidic and with a pH of about 5.8 (Obeng, 2000).

The Guinea Savannah zone of the northern part of Ghana has two distinct seasons (rainy season and dry season). The rainy season begins from May and ends around October. According to the MoFA (2013), the annual rainfall in the area varies between 750 mm and 1050 mm and has an estimated cropping period of between 180-200 days. The dry season begins from November and ends somewhere in March/April. High temperatures are recorded around March and April while low temperatures recorded around December and early January. The harmattan (northeast trade winds) which occurs between December to early February affects the temperature in the region considerably. The temperatures during the harmattan period varies between 14°C in the night and 40°C during the daytime. Because relative humidity is very low during harmattan, it reduces the intensity of the high temperature during daytime. The ecology of the area consists of vast grassland, which is interspersed with short trees without distinct storeys like in the forest ecology. The trees as described as drought-resistant trees and include dawadawa, shea, baobab, neem, acacia and mango among others.

**Determination of chemical constituents in the soil and the soil amendments**

Using a soil augur, ten (10) random soil samples were taken from the experimental plot at a depth of 15 cm. The samples were dried for 24 hours at 104 degrees Celsius in an oven. Following the drying process, they were thoroughly mixed, sieved, and ground into smaller particles. The percentages of nitrogen (N), organic carbon (C), elemental phosphorus (P), potassium (K), and pH (pH electrode) were then determined using representative samples and standard procedures. In addition to the soil samples from the Accra Compost and Recycling Plant (ACARP) compost, Decentralized Compost (DeCo), and Chicken Manure (CM) were examined for the presence of heavy metals, including copper (Cu), zinc (Zn), lead (Pb), and cadmium (Cd). Ethylenediamine tetracetic acid (EDTA) with ammonium acetate as the universal extractant was used to extract the heavy metals from the soil and composts. The Atomic Absorption Spectrophotometer was used to determine the heavy metals following extraction.

**Seed acquisition and nursery practices**

Farmers in Gbulahgu, a community in the Tolon district, and Builpela, a suburb in the Tamale metropolitan area, provided local cultivars of roselle and jute mallow. The seeds of both crops were raised in nursery boxes. In the nursery boxes, seeds were sown thinly in drilled lines, lightly covered with soil, mulched with light grass straw, and watered. Four weeks after seeding, the seedlings were transplanted into raised beds that had been prepared in the soil-amended plots.

**Field layout and soil amendment**

A randomized complete block design with four replications was used to set up the experiment. The seedlings were separated by 40 cm by 40 cm, and each plot measured 3 m by 3 m. In the experimental plots, the composts and CM were evenly distributed at a rate of 10 t/ha each. ACARP, DeCo, CM, and control were the treatments. A hand hoe was used to gently work these amendments into the soil, but the control plot received no amendment.

**Determination of chemical constituents in harvested roselle and jute mallow leaves**

Samples of dried roselle and jute mallow leaves weighing 0.5 grams were put in crucibles and heated to 450 degrees Celsius for three hours in a muffle furnace.

Ten milliliters of a 1:2 diluted nitric acid solution were then added to each sample after they had been taken out of the furnace and allowed to cool. The solutions were kept on a hot plate until they began to boil. After that, they were filtered into a 20 ml flask and filled with distilled water. After that, one milliliter of the mixture was injected into the AAS (Buck Scientific 210 VGP) flow injection tube to check for heavy metals. Next, the heavy metal concentration was computed using the formula below.

$$\text{Heavy metal concentration (ppm)} = C \times df$$

Where C – concentration of heavy metal from AAS reading and df – dilution factor (Motsara & Roy, 2008). From the sampling above, the hazard analysis was done using two factors, i.e. the bio-concentration factor and the hazard quotient. The bio-concentration factor (BCF) was determined after the determination of the heavy metal (Pb, Cd, Zn and Cu) concentrations in the soil as well as the composts this was done by dividing the concentration of each heavy metal in the dry leaves of roselle and jute mallow by that of the soil.

The health risk of the heavy metals to consumers was also determined by calculating their hazard quotients (HQ) as follows:

$$HQ = ADD/RfD = C \times EF \times ED/BW \times AT \times RfD$$

Where:
HQ = Hazard quotient (unitless)
ADD = Average daily dose (mg/kg-day)
RfD = Reference dose (mg/kg-day)
C = (mg/kg fresh weight basis) is the measured concentration of heavy metals on individual heavy metal basis in the edible part of the vegetable.
IR = (kg/day per person) is the amount of daily vegetable consumption.
NB: The average IR in Ghana is 0.137kg/day per person (Ruel, T. M., et al., 2005).
EF = (350days/year) is the exposure frequency to a particular heavy metal.
ED = the exposure duration (6years for child, 30 years for adult).
BW = the body weight (24.5kg for child, 60.3kg for adult).
AT = the average life time for non-carcinogens (ED-365 days/year).

The risk analysis (HQ) was done separately for an adult (body weight of 60kg) with an exposure duration of 30years and a child (body weight of 24.7kg) with an exposure duration of 6years.

**Data analysis**

The analysis of variance (ANOVA) on the data collected was carried out using GenStat statistical package 12$^{th}$ edition. Treatment means were separated at the 5% level of significance using the Fisher's least significant difference (LSD).

**Results**

**Heavy metals and other chemical constituents in the soil**

The presence and concentration of Cd, Pb, Zn, Cu, pH, N, P, K, and C were determined by the results of the soil analysis carried out prior to the application of the soil amendments; these results are shown in Table 1. With a pH of 4.4, organic carbon content of 2.0 %, and nitrogen content of 0.2 %, the soil was categorized as acidic. Zinc was 17.6 mg/kg, potassium was 261.3 mg/kg, phosphorus was 38.7 mg/kg, and copper was 6.5 mg/kg. Pb and Cd, two non-essential heavy metals, had concentrations of 5.5 mg/kg and 0.5 mg/kg, respectively.

**Table 1. Chemical properties of the Kpalsawgu soil series at the experimental site**

| Chemical properties | Concentration |
|---|---|
| pH | 4.4 |
| C | 2.0 (%) |
| N | 0.2 (%) |
| P | 38.7 (mg/kg) |
| K | 261.3 (mg/kg) |

| | |
|---|---|
| Zn | 17.6 (mg/kg) |
| Cd | 0.5 (mg/kg) |
| Pb | 5.5 (mg/kg) |
| Cu | 6.5 (mg/kg) |

The concentrations are means of three replicates on dry matter basis

**Heavy metals and other chemical constituents in CM, ACARP and DeCo composts**

The compost was found to be acidic, with pH values of 3.9 for CM, 4.3 for ACARP, and 4.8 for DeCo, as shown in Table 2. While the carbon content was 1.6 % for ACARP, 3.6 % for DeCo, and 7.5 % for CM, the nitrogen contents were 0.3 % for both ACARP and DeCo and 0.6 % for CM. The ACARP compost had the highest concentration of all the metals on average, followed by the CM and DeCo.

**Table 2. Heavy metals and other chemical constituents in CM, ACARP and DeCo composts**

| Chemical constituents | CM | ACARP Compost | DeCo compost |
|---|---|---|---|
| pH | 3.9 | 4.3 | 4.8 |
| C (%) | 7.5 | 1.6 | 3.6 |
| N (%) | 0.6 | 0.3 | 0.3 |
| P(mg/kg) | 72.3 | 59.6 | 79.1 |
| K(mg/kg) | 446.9 | 368.6 | 494.4 |
| Zn(mg/kg) | 3.2 | 19.5 | 1.8 |
| Cd(mg/kg) | 0.1 | 3.4 | 0.5 |
| Pb(mg/kg) | 0.7 | 4.2 | 1.6 |
| Cu(mg/kg) | 1.1 | 6.8 | 2.8 |

The concentrations are means of three replicates on dry matter basis.

**Application of organic soil amendments and its effect on heavy metal concentration in roselle and jute mallow**

The leaf samples of roselle and jute mallow contained residues of the heavy metals (Zn, Cu, Cd, and Pb) that were tested for (Table 3). In comparison to the other amended plots, the DeCo compost with roselle showed the highest Zn concentration (31.5 mg/kg) in the leaves. Although this differed significantly ($P \leq .05$) from ACARP and CM, it was comparable to the control plot. There were no appreciable variations between any of the amendments for Cu, Cd, or Pb. For jute mallow, the concentration of zinc in the leaves of the plot amended with the ACARP compost was 26.5 mg/kg (Table 4), which was considerably higher than that of the CM (16.6 mg/kg) and control (16.7 mg/kg) plots. The concentrations of Cu, Pb, and Cd in the leaves of the different amended plots did not differ significantly.

**Table 3. Application of organic soil amendments and its effect on heavy metal concentration in roselle**

| Organic Soil amendment | Zn (mg/kg) | Cu (mg/kg) | Cd (mg/kg) | Pb (mg/kg) |
|---|---|---|---|---|
| ACARP | 18.8 | 12.5 | 0.6 | 4.1 |
| DeCo | 31.5 | 11.5 | 1.1 | 5.9 |
| CM | 18.6 | 11.4 | 0.9 | 4.9 |

| | | | | |
|---|---|---|---|---|
| Control | 22.3 | 12.5 | 0.6 | 3.6 |
| **LSD (5%)** | **12.1** | **5.4** | **1.2** | **3.4** |

The concentrations are means of four replicates expressed on dry weight basis.

**Table 4. Application of organic soil amendments and its effect on heavy metal concentration of jute mallow**

| Organic soil amendment | Zn (mg/kg) | Cu (mg/kg) | Cd (mg/kg) | Pb (mg/kg) |
|---|---|---|---|---|
| ACARP | 26.5 | 17.6 | 0.6 | 6.7 |
| DeCo | 22.8 | 16.3 | 1.0 | 5.2 |
| CM | 16.6 | 15.3 | 0.4 | 5.4 |
| Control | 16.7 | 15.9 | 0.9 | 5.9 |
| **LSD (5%)** | **9.1** | **NS** | **NS** | **NS** |

The concentrations are means of four replicates expressed on dry weight basis.

**Bio-Concentration Factors (BCF) in roselle and jute mallow leaves due to the application of composts**

The concentration of each heavy metal in roselle and jute mallow was divided by the concentration of the heavy metal in the soil to determine the BCF. As shown in Table 5, the values were in the following decreasing order: Zn>Cu>Pb>Cd. This shows that the leaves of roselle and jute mallow have higher concentrations of the two essential heavy metals (Zn and Cu) and lower concentrations of the two non-essential heavy metals.

**Table 5. Bio-Concentration Factors (BCF) in roselle and jute mallow leaves due to the application of composts**

| Heavy metal type | BCF – roselle | BCF - jute mallow |
|---|---|---|
| Cd | 0.1 | 0.1 |
| Zn | 4.1 | 4.1 |
| Pb | 0.8 | 0.8 |
| Cu | 1.6 | 1.6 |

BCFs are means of three replicates expressed on dry matter basis.

**Determination of health risk of heavy metals (Pb and Cd) in leaves of roselle and jute mallow**

Both roselle and jute mallow had HQs for Zn and Cu below 1, which meant that neither adults nor children were at risk for health problems (Figures 1 and 2, respectively). On average, though, Pb and Cd could be dangerous to both adult and child populations. For adults, the risk was higher for roselle than for jute mallow, but it varied for children.

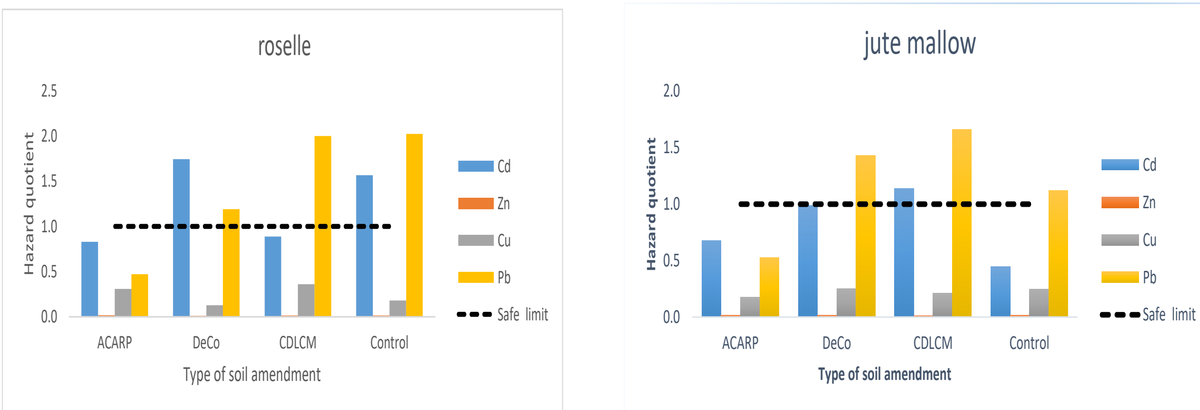


**Figure 1. Health risk of adults consuming heavy metals in leaves of roselle and jute mallow**

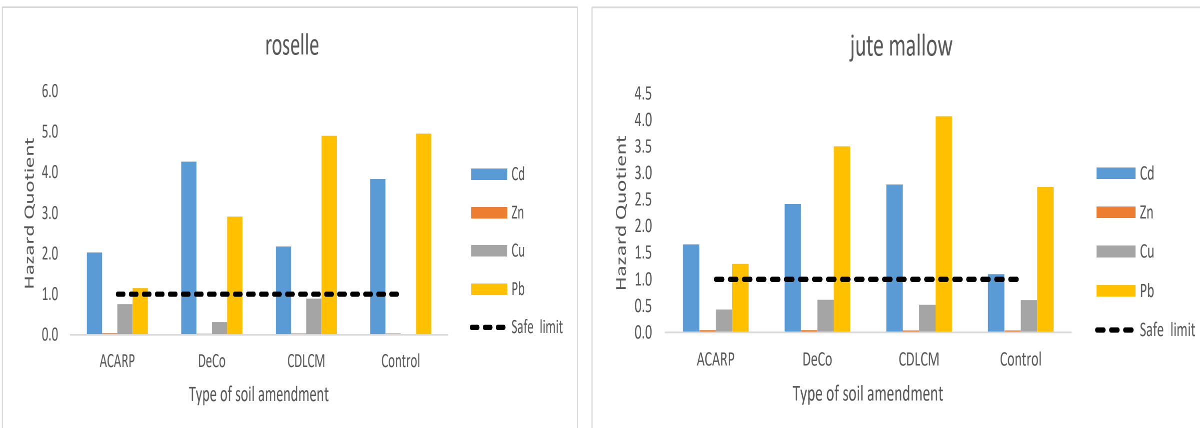


**Figure 2. Health risk of children consuming heavy metals in leaves of roselle and jute mallow**

## Discussion

### Concentration of heavy metal and other chemical constituents in the soil

The heavy metals (Cd, Pb, Cu and Zn) were found to be present in the study site. In this study, the heavy metals concentrations in the topsoil were 0.5 mg/kg Cd, 5.5 mg/kg Pb, 6.5 mg/kg Cu and 17.6 mg/kg Zn. These concentrations are similar to that of a study conducted by Ayari et al. (2010), in which they found that the top 0-20 cm of soil contained Cu, Zn, Pb and Cd and their concentrations were 48.23 mg/kg Cu, 92.12 mg/kg Zn, 55.22 mg/kg Pb and 1.10 mg/kg Cd.

The concentration (0.5 mg/kg) of cadmium in the soil fell in line with results of other studies conducted by Chaney (2012); Tchounwou et al. (2014) who indicated that, cadmium concentration normally ranges from 0.1 to 2 mg/ kg in most agricultural soils. In this study, the heavy metals concentrations in the topsoil were 0.5 mg/kg Cd, 5.5 mg/kg Pb, 6.5 mg/kg Cu and 17.6 mg/kg Zn. The concentrations of Cd and Pb reported in this study were considered characteristic for most soils as contained in the reports by WHO (2007) and by Biernacka & Maluszynski (2006).

Although other authors have reported much higher soil Cu concentrations of 50 mg/kg ATSDR (2004) and 1,300–1,400 mg/kg by Nachtigall et al., (2007)., however studies by Antonio and John (2013) and Pariera & Clain (2013) supported the idea that the concentration of the two essential heavy metals, Cu and Zn, in the soil was normal for plant growth and Suciu et al. (2008) reported the corresponding value of 1197.6 mg/kg. Additionally, Alloway (2008) reported higher Zn concentrations in soils (55 mg/kg). However, the Guinea Savanna soils' fertility status was reported in a joint report by IFPRI, IFDC, ILFSP, MSU, and IITA (2015) to Ghana's Ministry of Food and Agriculture. The report stated that the soils' pH ranged from 6.2 to 6.6, their organic carbon ranged from 0.51 to 0.99 percent, their total N ranged from 0.02 to 0.12 percent, and their available P and K ranged from 0.06 to 1.80 and 36.96 to 44.51 mg/kg, respectively. As a result of weathering processes during soil formation, heavy metals naturally occur in soils at trace and non - toxic levels (Kabata-Pendias, 2011). The soil's Cd (0.5 mg/kg) and Pb (5.5 mg/kg) concentrations were comparable to those reported by WHO (2007) and Biernacka & Maluszynski (2006) as typical values for the majority of soils. In another related research, Chaney (2012); Tchounwou et al. (2014) found that the typical range of Cd concentrations in agricultural soils is between 0.1 and 2 mg/kg. However, the soil's Pb concentration was below the 10-50 mg/kg threshold (ATSDR, 2012) and 1521.8 mg/kg threshold. (Suciu et al., 2008).

**Concentration of heavy metals and other chemical constituents in CM, ACARP and DeCo composts**

From the study, the Chicken Manure was found to contain the four heavy metals (Cd, Pb, Cu and Zn) analysed for. In support of this, is research by Delgado Arroyo et al., (2014); Agriculture and Agri-food Canada (1990) and Chastain et al., (n.d.) reported that poultry manure also contains heavy metals such as Pb, Cd, Zn, and Cu apart from the nutrients that it contains for plant growth. Across the amendments, the concentrations of the heavy metals on average ranged between 0.7 – 4.2 mg/kg for Pb, 0.1 – 3.4mg/kg for Cd, 1.1 – 6.8mg/kg for Cu and 1.8 – 19.5mg/kg for Zn in a similar study, Irshad et al. (2013), found the concentrations of Pb and Cd in chicken manure to be 28 mg/kg and 48 mg/kg, respectively. Additional research by Ayari et al. (2010) discovered that 337 mg/kg of Cu, 1174.5 mg/kg of Zn, 411.5 mg/kg of Pb, and 5.17 mg/kg of Cd were present in municipal solid waste compost. According to the European Commission's (2004) standards, ACARP could be rated as A+ (suitable for agriculture, including organic farming) based on their concentrations in this study, while DeCo and CM could be rated as A (suitable for agricultural production).

**Concentration of heavy metals in harvested leaves**

The levels of the two non-essential heavy metals, Cd and Pb, were found to be higher than the Maximum Residue Levels (MRLs) in this investigation. For the control, ACAPRP compost, DeCo compost, and CM treated plots, the concentrations of Cd in the harvested roselle leaves were found to be 0.6, 0.6, 1.1, and 0.9 mg/kg dry matter, respectively. The concentrations in jute mallow for the control, ACARP, DeCo, and CM treated plots were 0.9, 0.6, 1.0, and 0.4 mg/kg, respectively. The amounts were deemed significant when compared to the Codex Alimentarius Commission (FAO/WHO, 2011) and European Commission (EC, 2006) standards for the maximum residue level of 0.2 mg/kg for leafy vegetables, even though the values obtained in both roselle and jute mallow were not significantly different among the various amendments. For the control, ACARP, DeCo, and CM treated plots, the dry matter basis Pb concentrations in roselle were 3.6, 4.1, 5.9, and 4.9 mg/kg, respectively. In contrast, the corresponding values were 5.9, 6.7, 5.2, and 5.4 mg/kg.

**Potential health risk of heavy metals on adults and children**

Roselle and Jute Mallow had hazard quotients (HQ) of 6.3 and 4.0 for adults weighing 60 kg, respectively, and 15.4 and 9.8 for children weighing 24.5 kg. According to this study, children were more vulnerable than adults. Despite eating less than adults, children are more likely to consume heavy metals due to their lower body weight as related by SCOOP (2004). The HQ of Pb in Roselle and Jute Mallow was 7.3 and 5.7 in adults (60 kg body weight) and 18.0 and 13.9 in children (24.5 kg body weight). These results are consistent with a similar risk assessment conducted by Jena, V et al., 2012), who estimated the HQ of Pb in leafy vegetables to be 7.22. Zhou et al. (2016) conducted a related study and discovered that the target HQs for Pb and Cd in vegetables for adults and children were 1.15, 1.51, and 2.49, and 3.27, respectively. The WHO (2010) states that children's gastrointestinal absorption of lead is increased and up to the 50% of the lead that is consumed.

## Conclusion

From the study, cadmium and lead were present in CM, ACARP, and DeCo composts in addition to necessary elements like zinc and copper. It was also observed that the jute mallow and roselle cultivated on the soil amended with these composts contained residues of the heavy metals in the leaves. From the risk analysis, Pb and Cd residues in the leaves exceeded the MRLs by International standards making its continuous consumption a health hazard to the consumer. The outcome of this work paves the way for further investigation on other vegetables that can be consumed wholly to determine relative accumulation of residues in the various edible parts of the crop, it is also advised to undertake alternative strategies and integrated management practices for compost preparation and application to reduce the bioavailability of heavy metals in the production of vegetables.

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## Conflict of Interest Statement

Authors have declared that no competing interests exist.

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