

# Heavy metal bioaccumulation in *Telfairia occidentalis* cultivated in cassava mill effluent polluted and unpolluted soils in Aba Nigeria

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## Research Article

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# Abstract

Heavy metals bioaccumulation in fluted pumpkin (*Telfairia occidentalis*) cultivated in cassava effluent polluted and unpolluted soils was investigated using soil samples collected from five cassava processing sites in Aba, Abia State, Nigeria. Ten experimental units were established using bowls (21 cm diameter) filled with polluted and unpolluted soils. Plants grown in polluted soil were irrigated with cassava effluent, while control plants received water. Growth parameters, including germination time, shoot length, leaf number and yield, were monitored. Concentrations of Fe, As, Pb, Cd, Cu, Zn and Ni in leaves, shoots and fruits were determined using Atomic Absorption Spectrophotometry (AAS). Fluted pumpkins grown in unpolluted soil germinated earlier and exhibited significantly higher shoot length, leaf number and yield compared to those grown in polluted soil. Heavy metal concentrations were consistently higher in plants cultivated in effluent-polluted soil; however, measured values remained within current FAO/WHO permissible limits for vegetables. Given the potential toxicity and persistence of heavy metals in edible plants, continuous monitoring of vegetables cultivated in effluent-impacted soils is therefore recommended to safeguard food quality and public health.

## 1. Introduction

Heavy metals are among the most significant contaminants of leafy vegetables, including fluted pumpkin (*Telfairia occidentalis*). Plants cultivated on heavy metal contaminated soils can accumulate elevated levels of trace elements, thereby posing serious health risks to consumers [5]. Leafy vegetables are particularly prone to metal accumulation because metals can be absorbed not only through the roots but also via foliar deposition from the surrounding environment [6]. Sources of heavy metal contamination include the use of polluted irrigation water, fertilizers, metal-based pesticides, industrial emissions, transportation activities, and contamination during harvesting, storage, or at the point of sale. More recently, agricultural soils have also been affected by waste oil and cassava mill effluent pollution [5,8,10]. Humans and animals are exposed to these toxic metals primarily through plant uptake, which facilitates their transfer into the food chain. Since heavy metals are non-degradable and persistent, their accumulation in plant tissues constitutes a significant threat to public health and therefore requires continuous monitoring.

The mobility and bioavailability of metals in the environment are largely determined by their chemical reactivity, which influences their uptake by plants and subsequent exposure to humans through inhalation, drinking water, or consumption of contaminated food. Heavy metals are persistent environmental contaminants that can accumulate on plant surfaces and gradually penetrate plant tissues over time [9,10]. Consequently, plants growing in contaminated environments may absorb metals both from polluted soils through the roots and from atmospheric deposits on exposed plant surfaces.

The increasing concentration of heavy metals in the environment, particularly from anthropogenic sources such as cassava mill effluents (CME), has become a growing concern for environmental management [11–13]. Effluents generated from traditional cassava processing are major contributors to

environmental degradation, as they are often discharged untreated onto farmlands, streams, and surrounding ecosystems [14,15,16]. These effluents typically contain water, hydrocyanic acid, and organic waste materials, including peels and sieves from cassava pulp. Heavy metals present in cassava mill effluents can persist in the environment and bioaccumulate through soil-plant systems, thereby posing potential health risks to humans [17,18].

Fluted pumpkin (*Telfairia occidentalis*) is particularly vulnerable to heavy metal contamination due to its ability to absorb metals from both soil and atmospheric sources [19,20]. Consumption of fluted pumpkin cultivated on polluted soils may therefore expose consumers to elevated levels of toxic metals. Despite these concerns, information on the extent of heavy metal bioaccumulation in fluted pumpkin cultivated in cassava mill effluent-polluted soils, compared with unpolluted soils, remains limited in Aba, Abia State, Nigeria. Assessing the levels of metal accumulation in this widely consumed vegetable is therefore essential for evaluating potential health risks.

This study was designed to quantify the bioaccumulation of selected heavy metals in *Telfairia occidentalis* grown in cassava mill effluent-polluted and unpolluted soils in Aba, Nigeria, and to assess the implications for human health and environmental safety.

## **2. Materials and Methods**

### **2.1 Collection of Samples**

Ten soil samples were collected from five active cassava-processing locations in Aba, Abia State, Nigeria (7°21'30"E; 5°3'30"N) during the peak rainy season (August–October 2019). Sampling during this period was deliberately selected because increased soil moisture enhances the downward and lateral movement of soluble contaminants, thereby providing a more realistic representation of cassava mill effluent infiltration, dispersion, and metal mobility in agricultural soils.

Triplicate soil samples were obtained from each location, namely Iheorji, Iheorji Avenue, Umuogele, 16 Dike Road, and Owerri-Aba. Polluted soil samples were collected from sites that had experienced repeated cassava mill effluent discharge over several years, at a depth of 10 cm using sterile screw-cap containers. Unpolluted control soils were collected approximately 100 m away from each cassava mill to minimize contamination influence. All samples were immediately stored in ice-filled coolers, transported to the Chemistry Laboratory of Abia State Polytechnic within one hour, and analyzed within 24 hours to minimize physicochemical alterations.

### **2.2 Controlled Cultivation analysis**

A controlled cultivation experiment was conducted using ten experimental bowls adapted from the method described by Karunyal [21]. Five bowls were filled with cassava mill effluent-polluted soil, while the remaining five contained unpolluted soil and served as controls. Seeds of the same fluted pumpkin

(*Telfairia occidentalis*) variety were planted at uniform depth and spacing to ensure consistent germination and growth conditions.

To simulate agricultural practices in effluent-impacted farmlands, plants grown in polluted soils were irrigated every two days with freshly collected cassava mill effluent, whereas control plants received equal volumes of tap water. This dual-irrigation design was implemented to separate the effects of historical soil contamination from continuous effluent exposure, allowing a more accurate assessment of heavy-metal uptake dynamics.

Seedling emergence, shoot development, and leaf formation were monitored weekly. Plants were harvested after four weeks. Leaves, shoots, and fruits from both treatments were air-dried at ambient temperature and milled into fine powder to obtain homogeneous samples for metal analysis.

## 2.3 Heavy Metal Analysis

Concentrations of iron (Fe), lead (Pb), cadmium (Cd), arsenic (As), zinc (Zn), copper (Cu), and nickel (Ni) in plant tissues were quantified using a PerkinElmer Atomic Absorption Spectrophotometer (AAS) following established standard protocols. Instrument calibration was performed using certified reference standards to ensure accuracy and reproducibility.

## 2.4 Growth Assessment

Germination time was recorded by noting the exact day of seedling emergence. Shoot height was measured using a calibrated ruler, while the number of leaves and fruit yield were counted manually. These measurements provided an integrated evaluation of plant performance under effluent-polluted and unpolluted soil conditions.

## 2.5 Data analysis

All data were subjected to one-way analysis of variance (ANOVA) using IBM SPSS Statistics version 23 to determine significant differences in heavy-metal concentrations and growth parameters between plants cultivated in polluted and unpolluted soils. Statistical significance was evaluated at  $P < 0.05$ .

## 3. Results

The effects of cassava mill effluent–polluted soil on the growth and yield parameters of fluted pumpkin are presented in Table 1 and Plate 1. Germination time in effluent-polluted soil ranged from  $12 \pm 2.45$  to  $18 \pm 0.92$  days across the study locations. Shoot length varied between  $7 \pm 1.92$  and  $12 \pm 1.85$  mm, while the number of leaves ranged from  $8 \pm 1.41$  to  $15 \pm 2.45$ . Fruit yield was generally low, with values ranging from 0 to  $1 \pm 0.92$ , indicating reduced productivity in effluent-impacted soils.

Table 1  
Effect of cassava mill effluent polluted soil on the germination of fluted Pumpkin

| Germination of fluted Pumpkin | Cassava mill location |                |           |             |            |
|-------------------------------|-----------------------|----------------|-----------|-------------|------------|
|                               | Iheorji               | Iheorji Avenue | Umuogele  | 16Dike Road | Owerri Aba |
| Germination time              | 18 ± 0.92             | 15 ± 2.77      | 17 ± 2.33 | 12 ± 2.45   | 12 ± 2.82  |
| Shoot length (mm)             | 10 ± 1.07             | 12 ± 1.85      | 7 ± 1.92  | 10 ± 1.41   | 9 ± 2.45   |
| Number of leaves              | 12 ± 1.41             | 15 ± 2.45      | 9 ± 1.85  | 10 ± 2.33   | 8 ± 1.41   |
| Number of yields              | 1 ± 0.53              | 0              | 1 ± 1.07  | 0           | 1 ± 0.92   |

Iheorji Iheorji Avenue Umuogele 16 Dike Road Owerri Aba

### Plate 1

Effect of cassava mill effluent-polluted soil on the growth and yield of fluted pumpkins

The growth and yield performance of fluted pumpkin cultivated in unpolluted soil is shown in Table 2 and Plate 2. Germination occurred earlier in unpolluted soils, with germination time ranging from 9 ± 0.92 to 12 ± 1.85 days. Shoot length ranged between 12 ± 4.23 and 25 ± 6.30 mm, while the number of leaves varied from 6 ± 2.99 to 20 ± 9.67. Fruit yield ranged from 0 to 2 ± 1.13, indicating improved growth and productivity compared with plants grown in effluent-polluted soil.

Table 2  
Effect of effluent unpolluted soil on the germination of fluted pumpkin

| Germination of fluted Pumpkin | Cassava mill location |                    |            |             |            |
|-------------------------------|-----------------------|--------------------|------------|-------------|------------|
|                               | Iheorji               | Iheorji Avenue     | Umuogele   | 16Dike Road | Owerri Aba |
| Germination time              | 12 ± 1.848            | 13 ± 2.772         | 10 ± 0.924 | 10 ± 0.924  | 9 ± 0.924  |
| Shoot length (mm)             | 12 ± 4.23             | 20 ± 5.186 ± 2.990 | 15 ± 4.53  | 22 ± 6.88   | 25 ± 6.30  |
| Number of leaves              | 19 ± 2.34             | 17 ± 5.99          | 20 ± 5.99  | 16 ± 5.88   | 20 ± 9.67  |
| Number of yields              | 1 ± 1.07              |                    | 0          | 1 ± 1.13    | 2 ± 1.13   |

Iheorji Iheorji Avenue Umuogele 16 Dike Road Owerri Aba

### Plate 2

Effect of unpolluted soil on the growth and yield of fluted pumpkin

The concentrations of heavy metals in the leaves of fluted pumpkin cultivated in cassava mill effluent–polluted soil are presented in Table 3. Iron concentrations ranged from  $0.89 \pm 0.011$  to  $2.08 \pm 0.178$  mg/g, while lead ranged between  $0.65 \pm 0.011$  and  $1.21 \pm 0.119$  mg/g. Cadmium ranged from  $0.51 \pm 0.052$  to  $0.72 \pm 0.019$  mg/g, arsenic from  $0.41 \pm 0.063$  to  $0.85 \pm 0.023$  mg/g, zinc from  $0.59 \pm 0.011$  to  $0.76 \pm 0.039$  mg/g, copper from  $0.52 \pm 0.060$  to  $0.74 \pm 0.011$  mg/g, and nickel from  $0.41 \pm 0.039$  to  $0.62 \pm 0.034$  mg/g.

Table 3  
Heavy metal content of the leaves of fluted pumpkins from cassava mill effluent-polluted soil

| Heavy metals   | Cassava mill location |                  |                  |                  |                  |
|----------------|-----------------------|------------------|------------------|------------------|------------------|
|                | Iheorji               | Iheorji Avenue   | Umuogele         | 16Dike Road      | Owerri Aba       |
| Iron (mg/g)    | $1.81 \pm 0.063$      | $2.08 \pm 0.178$ | $1.21 \pm 0.019$ | $0.89 \pm 0.011$ | $1.33 \pm 0.011$ |
| Lead (mg/g)    | $1.21 \pm 0.119$      | $0.79 \pm 0.178$ | $0.84 \pm 0.024$ | $0.65 \pm 0.011$ | $0.77 \pm 0.011$ |
| Cadmium (mg/g) | $0.67 \pm 0.041$      | $0.51 \pm 0.052$ | $0.72 \pm 0.019$ | $0.55 \pm 0.023$ | $0.69 \pm 0.023$ |
| Arsenic (mg/g) | $0.53 \pm 0.059$      | $0.41 \pm 0.063$ | $0.61 \pm 0.030$ | $0.81 \pm 0.011$ | $0.85 \pm 0.023$ |
| Zinc (mg/g)    | $0.66 \pm 0.023$      | $0.76 \pm 0.039$ | $0.59 \pm 0.011$ | $0.61 \pm 0.011$ | $0.71 \pm 0.023$ |
| Copper (mg/g)  | $0.61 \pm 0.041$      | $0.52 \pm 0.060$ | $0.74 \pm 0.011$ | $0.53 \pm 0.033$ | $0.67 \pm 0.045$ |
| Nickel (mg/g)  | $0.41 \pm 0.039$      | $0.45 \pm 0.030$ | $0.54 \pm 0.011$ | $0.61 \pm 0.011$ | $0.62 \pm 0.034$ |

The heavy metal content of fluted pumpkin leaves grown in unpolluted soil is presented in Table 4. Iron concentrations ranged from  $0.51 \pm 0.012$  to  $0.81 \pm 0.022$  mg/g, while lead ranged between  $0.11 \pm 0.019$  and  $0.41 \pm 0.023$  mg/g. Cadmium ranged from  $0.08 \pm 0.028$  to  $0.16 \pm 0.057$  mg/g, arsenic from  $0.12 \pm 0.012$  to  $0.51 \pm 0.023$  mg/g, zinc from  $0.05 \pm 0.037$  to  $0.41 \pm 0.013$  mg/g, copper from  $0.11 \pm 0.019$  to  $0.25 \pm 0.045$  mg/g, and nickel from  $0.04 \pm 0.009$  to  $0.18 \pm 0.010$  mg/g.

Table 4  
Heavy metals content of the leaves of fluted pumpkin from the unpolluted soil

| Heavy metals   | Cassava mill location |                |              |              |              |
|----------------|-----------------------|----------------|--------------|--------------|--------------|
|                | Iheorji               | Iheorji Avenue | Umuogele     | 16Dike Road  | Owerri Aba   |
| Iron (mg/g)    | 0.81 ± 0.022          | 0.66 ± 0.203   | 0.62 ± 0.019 | 0.51 ± 0.012 | 0.55 ± 0.171 |
| Lead (mg/g)    | 0.41 ± 0.023          | 0.31 ± 0.010   | 0.11 ± 0.019 | 0.16 ± 0.034 | 0.21 ± 0.023 |
| Cadmium (mg/g) | 0.15 ± 0.034          | 0.08 ± 0.028   | 0.09 ± 0.028 | 0.12 ± 0.024 | 0.16 ± 0.057 |
| Arsenic (mg/g) | 0.21 ± 0.012          | 0.05 ± 0.037   | 0.05 ± 0.037 | 0.41 ± 0.013 | 0.25 ± 0.068 |
| Zinc (mg/g)    | 0.31 ± 0.013          | 0.16 ± 0.027   | 0.11 ± 0.019 | 0.23 ± 0.045 | 0.25 ± 0.010 |
| Copper (mg/g)  | 0.25 ± 0.045          | 0.04 ± 0.009   | 0.09 ± 0.028 | 0.11 ± 0.113 | 0.21 ± 0.045 |
| Nickel (mg/g)  | 0.18 ± 0.010          |                |              |              | 0.07 ± 0.034 |

One-way analysis of variance (ANOVA) revealed significant differences between cassava mill effluent-polluted and unpolluted soils in the concentrations of iron ( $F = 14.41$ ,  $p = 0.005$ ), lead ( $F = 31.52$ ,  $p = 0.001$ ), cadmium ( $F = 132.07$ ,  $p < 0.001$ ), zinc ( $F = 33.37$ ,  $p < 0.001$ ), and copper ( $F = 74.51$ ,  $p < 0.001$ ) in the leaves of fluted pumpkin (Tables 3 and 4; Appendix I). However, no significant differences were observed for arsenic ( $F = 3.02$ ,  $p = 0.120$ ) and nickel ( $F = 3.90$ ,  $p = 0.084$ ).

The concentrations of heavy metals in the shoots of fluted pumpkin cultivated in cassava mill effluent-polluted soil are presented in Table 5. Iron concentrations ranged from  $0.89 \pm 0.011$  to  $1.22 \pm 0.260$  mg/g, while lead ranged between  $0.67 \pm 0.385$  and  $0.89 \pm 0.385$  mg/g. Cadmium concentrations varied from  $0.56 \pm 0.045$  to  $0.75 \pm 0.223$  mg/g, and arsenic ranged from  $0.68 \pm 0.019$  to  $0.81 \pm 0.023$  mg/g. Zinc concentrations ranged between  $0.54 \pm 0.068$  and  $0.81 \pm 0.023$  mg/g, copper between  $0.51 \pm 0.023$  and  $0.79 \pm 0.113$  mg/g, and nickel between  $0.49 \pm 0.123$  and  $0.62 \pm 0.024$  mg/g.

Table 5

Heavy metals content of the shoot of fluted pumpkin from cassava mill effluent-polluted soil

| Heavy metals   | Cassava mill location |                  |                  |                  |                  |
|----------------|-----------------------|------------------|------------------|------------------|------------------|
|                | Iheorji               | Iheorji Avenue   | Umuogele         | 16Dike Road      | Owerri Aba       |
| Iron (mg/g)    | $0.89 \pm 0.011$      | $1.09 \pm 0.113$ | $1.22 \pm 0.260$ | $0.91 \pm 0.028$ | $0.99 \pm 0.093$ |
| Lead (mg/g)    | $0.89 \pm 0.011$      | $0.67 \pm 0.385$ | $0.72 \pm 0.023$ | $0.82 \pm 0.027$ | $0.79 \pm 0.216$ |
| Cadmium (mg/g) | $0.72 \pm 0.023$      | $0.61 \pm 0.023$ | $0.75 \pm 0.223$ | $0.56 \pm 0.045$ | $0.72 \pm 0.023$ |
| Arsenic (mg/g) | $0.81 \pm 0.023$      | $0.69 \pm 0.126$ | $0.68 \pm 0.019$ | $0.71 \pm 0.023$ | $0.69 \pm 0.204$ |
| Zinc (mg/g)    | $0.61 \pm 0.023$      | $0.81 \pm 0.023$ | $0.72 \pm 0.023$ | $0.54 \pm 0.068$ | $0.77 \pm 0.091$ |
| Copper (mg/g)  | $0.51 \pm 0.023$      | $0.62 \pm 0.079$ | $0.61 \pm 0.023$ | $0.79 \pm 0.113$ | $0.71 \pm 0.068$ |
| Nickel (mg/g)  | $0.49 \pm 0.123$      | $0.55 \pm 0.091$ | $0.55 \pm 0.138$ | $0.61 \pm 0.023$ | $0.62 \pm 0.024$ |

The heavy metals content of the shoot of fluted pumpkin from the unpolluted soil are presented in Table 6. Iron ranged between  $0.12 \pm 0.029$ – $0.51 \pm 0.012$  mg/g; lead,  $0.05 \pm 0.014$ – $0.16 \pm 0.057$  mg/g; cadmium,  $0.08 \pm 0.034$ – $0.31 \pm 0.013$  mg/g; arsenic,  $0.11 \pm 0.013$ – $0.21 \pm 0.010$  mg/g; zinc,  $0.07 \pm 0.023$ – $0.15 \pm 0.045$  mg/g; copper,  $0.11 \pm 0.012$ – $0.31 \pm 0.068$  mg/g and nickel,  $0.06 \pm 0.001$ – $0.15 \pm 0.056$  mg/g.

Table 6

Heavy metals content of the shoot of fluted pumpkins from the unpolluted soil

| Heavy metals | Cassava mill location |                |          |             |            |
|--------------|-----------------------|----------------|----------|-------------|------------|
|              | Iheorji               | Iheorji Avenue | Umuogele | 16Dike Road | Owerri Aba |

Shoots of fluted pumpkin cultivated in cassava mill effluent–polluted soil accumulated higher concentrations of all measured metals compared to unpolluted soils (Tables 5 and 6). Iron ranged from  $0.89 \pm 0.011$ – $1.22 \pm 0.260$  mg/g in polluted soils versus  $0.12 \pm 0.029$ – $0.51 \pm 0.012$  mg/g in unpolluted soils. Cadmium, arsenic, copper, and nickel were also markedly elevated in polluted soils. ANOVA revealed significant effects of soil type on iron, cadmium, arsenic, copper, and nickel ( $P < 0.05$ ) (Appendix III).

The heavy metals content of the fruits of fluted pumpkin from cassava mill effluent-polluted soil are presented in Table 7. Iron ranged between  $0.00$ – $0.72 \pm 0.555$  mg/g; lead,  $0.00$ – $0.61 \pm 0.012$  mg/g;

cadmium,  $0.00 - 0.51 \pm 0.012$  mg/g; arsenic,  $0.00 - 0.71 \pm 0.102$ mg/g; zinc,  $0.00 - 0.63 \pm 0.068$ mg/g; copper,  $0.00 - 0.55 \pm 0.068$  mg/g and nickel,  $0.00 - 0.46 \pm 0.034$ mg/g.

Table 7  
Heavy metals content of the fruits of fluted pumpkin from cassava mill effluent-polluted soil

| Heavy metals   | Cassava mill location |                |                  |             |                  |
|----------------|-----------------------|----------------|------------------|-------------|------------------|
|                | Iheorji               | Iheorji Avenue | Umuogele         | 16Dike Road | Owerri Aba       |
| Iron (mg/g)    | $0.72 \pm 0.555$      | 0.00           | $0.61 \pm 0.101$ | 0.00        | $0.51 \pm 0.012$ |
| Lead (mg/g)    | $0.61 \pm 0.012$      | 0.00           | $0.49 \pm 0.023$ | 0.00        | $0.51 \pm 0.013$ |
| Cadmium (mg/g) | $0.44 \pm 0.079$      | 0.00           | $0.51 \pm 0.012$ | 0.00        | $0.49 \pm 0.105$ |
| Arsenic (mg/g) | $0.61 \pm 0.011$      | 0.00           | $0.56 \pm 0.034$ | 0.00        | $0.71 \pm 0.102$ |
| Zinc (mg/g)    | $0.49 \pm 0.112$      | 0.00           | $0.51 \pm 0.012$ | 0.00        | $0.63 \pm 0.068$ |
| Copper (mg/g)  | $0.52 \pm 0.023$      | 0.00           | $0.42 \pm 0.022$ | 0.00        | $0.55 \pm 0.068$ |
| Nickel (mg/g)  | $0.39 \pm 0.034$      | 0.00           | $0.45 \pm 0.055$ | 0.00        | $0.46 \pm 0.034$ |

The heavy metals content of the fruits of fluted pumpkin from the unpolluted soil are shown in Table 8. Iron ranged between  $0.00 - 0.49 \pm 0.113$  mg/g; lead,  $0.00 - 0.21 \pm 0.091$  mg/g; cadmium,  $0.00 - 0.21 \pm 0.091$  mg/g; arsenic,  $0.00 - 0.15 \pm 0.023$  mg/g; zinc,  $0.00 - 0.25 \pm 0.058$  mg/g; copper,  $0.00 - 0.17 \pm 0.024$  mg/g and nickel,  $0.00 - 0.11 \pm 0.022$  mg/g.

Table 8  
Heavy metals content of the fruits of fluted pumpkin from the unpolluted soil

| Heavy metals   | Cassava mill location |                |          |              |              |
|----------------|-----------------------|----------------|----------|--------------|--------------|
|                | Iheorji               | Iheorji Avenue | Umuogele | 16Dike Road  | Owerri Aba   |
| Iron (mg/g)    | 0.49 ± 0.113          | 0.21 ± 0.023   | 0.00     | 0.31 ± 0.012 | 0.42 ± 0.011 |
| Lead (mg/g)    | 0.12 ± 0.034          | 0.15 ± 0.057   | 0.00     | 0.21 ± 0.091 | 0.11 ± 0.092 |
| Cadmium (mg/g) | 0.08 ± 0.023          | 0.11 ± 0.012   | 0.00     | 0.04 ± 0.034 | 0.09 ± 0.034 |
| Arsenic (mg/g) | 0.12 ± 0.031          | 0.09 ± 0.024   | 0.00     | 0.11 ± 0.013 | 0.09 ± 0.023 |
| Zinc (mg/g)    | 0.25 ± 0.058          | 0.17 ± 0.024   | 0.00     | 0.26 ± 0.023 | 0.15 ± 0.019 |
| Copper (mg/g)  | 0.17 ± 0.045          | 0.11 ± 0.024   | 0.00     | 0.08 ± 0.011 | 0.11 ± 0.019 |
| Nickel (mg/g)  | 0.09 ± 1.132          | 0.09 ± 0.023   | 0.00     | 0.11 ± 0.022 | 0.12 ± 0.114 |
|                |                       |                |          |              | 0.08 ± 0.010 |

The fruits of fluted pumpkin showed lower overall heavy metal accumulation compared to leaves and shoots (Tables 7 and 8). Fruits from polluted soils had iron concentrations ranging from 0.00–0.72 ± 0.555 mg/g, lead 0.00–0.61 ± 0.012 mg/g, and cadmium 0.00–0.51 ± 0.012 mg/g. Fruits from unpolluted soils had correspondingly lower levels. ANOVA indicated that soil type had no significant effect ( $P > 0.05$ ) on the accumulation of iron, lead, cadmium, arsenic, zinc, copper, or nickel in the fruits (Appendix IV).

The Food and Agriculture Organization (FAO) and World Health Organization (WHO) permissible limits for heavy metals in vegetables are presented in Table 9. These guideline values were used as reference standards for evaluating the safety of heavy metal concentrations detected in fluted pumpkin tissues in the present study.

**Table 9:** World Health Organization Tolerance limit for heavy metals in vegetables

| Heavy metals  | FAO/WHO (1989) tolerance limit value (mg/g) |
|---------------|---------------------------------------------|
| Iron (Fe)     | 0.4255                                      |
| Lead (Pb)     | 0.0003                                      |
| Cadmium (Cd)  | 0.0002                                      |
| Arsenic (*As) | 0.00001                                     |
| Zinc (Zn)     | 0.0994                                      |
| Copper (Cu)   | 0.0733                                      |
| Copper (Cu)   | 0.0679                                      |

## 4. Discussion

The germination time of fluted pumpkin in cassava mill effluent–polluted soil ranged from  $12 \pm 2.45$  to  $18 \pm 0.92$  days, whereas that in unpolluted soil ranged from  $9 \pm 0.924$  to  $12 \pm 1.848$  days (Tables 1–2). Several crops sown in uncontaminated soil germinated within the typical range for fluted pumpkin (10–12 days), while those planted in effluent-polluted soil experienced delayed germination. This delay is likely due to the highly acidic nature of the cassava mill effluent, which can negatively influence seed water uptake and enzymatic activity. These findings agrees with Komolafe [22], who reported that industrial effluent at higher concentrations inhibited the germination and growth of kidney beans. Similarly, Nadgórska-Socha et al. [23] observed reduced seed germination efficiency at lower pH levels caused by effluent exposure.

The shoot length of fluted pumpkin grown in effluent-polluted soil ranged from  $7 \pm 1.92$  to  $12 \pm 1.85$  mm, whereas shoot lengths in unpolluted soil ranged from  $12 \pm 4.23$  to  $25 \pm 6.30$  mm (Tables 1–2). Plants in unpolluted soil consistently produced taller shoots, suggesting that effluent pollution inhibits vegetative growth. This is in agreement with Ehi et al. [24], who reported significant reductions in plant height with increasing cassava mill effluent application in greenhouse trials. While plants require certain heavy metals as micronutrients for growth [25], concentrations above optimal levels (pH 5.5–6.5) can disrupt physiological processes and reduce growth [26].

The number of leaves for fluted pumpkin in effluent-polluted soil ranged from  $8 \pm 1.41$  to  $15 \pm 2.45$ , while that in unpolluted soil ranged from  $6 \pm 2.99$  to  $20 \pm 9.67$  (Tables 1–2). Leaf production was generally higher in unpolluted soils, indicating that effluent exposure inhibits foliar development, possibly due to heavy metal stress. This observation aligns with Ehi et al. [24], who reported a significantly higher number of leaves in fluted pumpkin grown with reduced effluent treatment compared to higher effluent levels.

Fruit yield in effluent-polluted soil ranged from 0 to  $1 \pm 0.92$ , compared with 0 to  $2 \pm 1.13$  in unpolluted soil (Tables 1–2). The higher yields in unpolluted soils are likely due to better nutrient availability and

reduced toxic stress. Seedlings irrigated with clean water grew more vigorously throughout the experimental period than those irrigated with effluent. According to Amakiri and Onofeghara [27], any factor that adversely affects germination can cascade to reduce overall growth and yield.

The one-way analysis of variance (ANOVA) indicated that cassava mill effluent-polluted and unpolluted soils had significant effects ( $P < 0.05$ ) on shoot length and number of leaves, whereas differences in germination time and fruit yield were not statistically significant ( $P > 0.05$ ). This suggests that while effluent pollution strongly influences vegetative growth parameters, early germination and reproductive output may be less sensitive to soil contamination under the experimental conditions (Appendix I).

The iron content of the leaves of fluted pumpkin from untreated cassava mill effluent-polluted soil ranged from  $0.89 \pm 0.011$  to  $2.08 \pm 0.178$  mg/g, while leaves from unpolluted soil contained  $0.51 \pm 0.012$  to  $0.81 \pm 0.022$  mg/g (Tables 3–4). Iron concentrations were higher in effluent-polluted soil, indicating enhanced uptake due to soil contamination. Lami et al. [28] reported iron levels of 0.0251–0.0673 mg/g for contaminated soil in fluted pumpkin leaves, whereas Edem et al. [29] observed 0.00314 mg/g in Cross River and Akwa Ibom States. The elevated iron in this study may result from iron-rich soils, proximity to rusted iron materials, and deposition of iron oxides, as observed from reddish-brown streaks in the soil. Iron accumulation in leaves can have nutritional benefits, serving as a blood tonic and remedy for anaemia [28].

The lead content in leaves from effluent-polluted soil ranged from  $0.65 \pm 0.011$  to  $1.21 \pm 0.119$  mg/g, while unpolluted soils had  $0.11 \pm 0.019$  to  $0.41 \pm 0.023$  mg/g (Tables 3–4). Higher lead levels in polluted soils likely result from anthropogenic sources such as agrochemicals, automobile workshops, lead batteries, paint, gasoline, and electronic waste. Previous studies reported lead in fluted pumpkin leaves at 3.97–56.6 mg/kg in contaminated soil [28] and 0.164 mg/kg in Makurdi vegetables [30]. Lead accumulation poses serious health risks including anemia, neurotoxicity, and kidney damage [31].

Cadmium levels in leaves from polluted soil ranged from  $0.51 \pm 0.052$  to  $0.72 \pm 0.019$  mg/g, compared with  $0.08 \pm 0.028$  to  $0.16 \pm 0.057$  mg/g in unpolluted soil (Tables 3–4). This indicates that effluent discharge is a significant source of cadmium contamination. Cadmium is extremely toxic even at low concentrations, affecting organs such as the liver, kidneys, lungs, bones, placenta, brain, and central nervous system [33, 34]. Chronic exposure can also cause learning disabilities and hyperactivity in children.

Arsenic content in leaves from effluent-polluted soil ranged from  $0.41 \pm 0.063$  to  $0.85 \pm 0.023$  mg/g, while unpolluted soil contained  $0.12 \pm 0.024$  to  $0.51 \pm 0.023$  mg/g (Tables 3–4). Higher arsenic levels in polluted soils may reflect contamination from effluent irrigation or soil accumulation. Chronic consumption of arsenic-contaminated vegetables may lead to kidney and liver damage, gastrointestinal issues, peripheral neuropathy, skin lesions, and increased cancer risk [35, 36].

Zinc content in leaves from effluent-polluted soil ranged from  $0.59 \pm 0.011$  to  $0.76 \pm 0.039$  mg/g, whereas unpolluted soils contained  $0.05 \pm 0.037$  to  $0.41 \pm 0.013$  mg/g (Tables 3–4). Elevated zinc in polluted soils

is likely due to effluent input and soil composition. Zinc is essential for immune function, wound healing, blood clotting, and nucleic acid metabolism; however, excess zinc can cause renal damage, vomiting, and cramps [37, 39].

Copper content in leaves ranged from  $0.52 \pm 0.060$  to  $0.74 \pm 0.011$  mg/g in polluted soil, compared with  $0.11 \pm 0.019$  to  $0.25 \pm 0.045$  mg/g in unpolluted soil (Tables 3–4). The higher copper content in polluted soils is consistent with effluent contamination. Copper is essential for enzymatic activity, but excessive amounts can cause gastrointestinal disorders. Fluted pumpkin leaves with moderate copper levels may have medicinal benefits for treating diarrhea, anemia, and other conditions [40].

Nickel content ranged from  $0.41 \pm 0.039$  to  $0.62 \pm 0.034$  mg/g in polluted soils and  $0.04 \pm 0.009$  to  $0.18 \pm 0.010$  mg/g in unpolluted soils (Tables 3–4). Nickel uptake is influenced by leaf morphology and exposure to aerial deposition [41]. Both deficiency and excess of nickel can adversely affect human health, causing metabolic, cardiovascular, and respiratory issues, and even increasing cancer risk [42–44].

The significantly higher concentrations of iron, lead, cadmium, zinc, and copper in fluted pumpkin leaves grown on cassava mill effluent–polluted soils indicate that effluent discharge contributes substantially to heavy metal accumulation. This accumulation poses ecological and human health risks due to the toxic nature of these metals. In contrast, the absence of statistically significant differences for arsenic and nickel suggests limited mobility or uptake under prevailing soil and environmental conditions.

The one-way analysis of variance (ANOVA) confirmed that the type of soil (effluent-polluted vs. unpolluted) had significant effects ( $P < 0.05$ ) on iron, lead, cadmium, zinc, and copper in fluted pumpkin leaves. No significant differences were observed for arsenic and nickel ( $P > 0.05$ ), indicating that these metals were less influenced by soil contamination in this study (Appendix II).

The iron content of the shoots of fluted pumpkin from untreated cassava mill effluent–polluted soil ranged from  $0.89 \pm 0.011$  to  $1.22 \pm 0.260$  mg/g, while shoots from unpolluted soil contained between  $0.12 \pm 0.029$  and  $0.51 \pm 0.012$  mg/g (Tables 5–6). Iron concentrations were consistently higher in plants grown on effluent-polluted soils, indicating enhanced uptake under contaminated conditions. Fluted pumpkins cultivated on heavy-metal-contaminated sites are known to accumulate higher metal concentrations than those grown on uncontaminated soils due to absorption through the root system [45]. This observation agrees with the findings of Edem et al. [29], who reported iron concentrations ranging from 0.82 to 1.12 mg/g in similar soil–plant systems. Prolonged consumption of vegetables containing elevated iron and other metals may pose long-term health concerns, highlighting the importance of routine monitoring of heavy metals in food crops to prevent excessive bioaccumulation in the food chain [35, 46].

The lead content of the shoots of fluted pumpkin from untreated cassava mill effluent–polluted soil ranged from  $0.67 \pm 0.385$  to  $0.89 \pm 0.011$  mg/g, whereas shoots from unpolluted soil ranged from  $0.05 \pm 0.014$  to  $0.16 \pm 0.057$  mg/g (Tables 5–6). Higher lead concentrations in polluted soils may be attributed

to soil contamination from anthropogenic sources such as traffic emissions, agrochemicals, and industrial residues. Lead tends to accumulate in surface soils and strongly binds to organic matter, with its availability influenced by soil particle size, cation exchange capacity, and plant physiological factors including root surface area and transpiration rate [48]. Obasi et al. [44] similarly reported lead concentrations in *Telfairia occidentalis* shoots exceeding WHO maximum permissible limits, supporting the trend observed in the present study.

Cadmium, a non-essential and highly toxic metal, accumulates primarily in the kidneys and liver following dietary exposure [49]. The cadmium content of fluted pumpkin shoots ranged from  $0.56 \pm 0.045$  to  $0.75 \pm 0.223$  mg/g in polluted soil and from  $0.08 \pm 0.034$  to  $0.31 \pm 0.013$  mg/g in unpolluted soil (Tables 5–6). The elevated cadmium levels in effluent-polluted soils suggest sustained environmental inputs from cassava processing waste. Although Sobukola et al. [51] reported lower cadmium concentrations in fluted pumpkin from Lagos markets, cadmium remains strongly phytotoxic and interferes with plant physiological processes, including enzyme activity, stomatal function, and nutrient uptake [52–54]. High cadmium exposure may result in reduced biomass production and overall growth inhibition in plants [55, 56].

The arsenic content of the shoots of fluted pumpkin ranged from  $0.68 \pm 0.019$  to  $0.81 \pm 0.023$  mg/g in effluent-polluted soil and from  $0.11 \pm 0.013$  to  $0.21 \pm 0.010$  mg/g in unpolluted soil (Tables 5–6). Higher arsenic concentrations in polluted soils may be linked to the use of arsenic-containing fertilizers and agro-inputs. Alam et al. [35] reported similar arsenic accumulation in vegetables grown in contaminated environments, noting associated health risks to both humans and animals consuming such produce.

Zinc concentrations in shoots from effluent-polluted soils ranged from  $0.54 \pm 0.068$  to  $0.81 \pm 0.023$  mg/g, while those from unpolluted soils ranged from 0.07 to 0.15 mg/g (Tables 5–6). Excess zinc accumulation may lead to phytotoxic effects, including impaired metabolic activity and growth retardation. Although zinc is an essential micronutrient for both plants and humans, elevated soil zinc levels can inhibit root and shoot development [60]. The high zinc uptake observed may also indicate the potential use of fluted pumpkin in phytoremediation of zinc-contaminated soils [59].

Copper, an essential micronutrient involved in enzymatic reactions and iron metabolism [61], showed concentrations ranging from  $0.51 \pm 0.023$  to  $0.79 \pm 0.113$  mg/g in shoots grown on polluted soil and from  $0.11 \pm 0.012$  to  $0.24 \pm 0.046$  mg/g in shoots from unpolluted soil (Tables 5–6). The higher copper levels in polluted soils likely reflect increased availability from effluent contamination. Comparable copper concentrations have been reported by Edem et al. [29] and Sobukola et al. [51] in similar studies.

Vegetables are an essential component of the human diet, providing vital nutrients such as vitamins, minerals, and proteins [63]. However, heavy metal contamination of vegetables remains a major concern for food safety and quality assurance [64]. The nickel content of fluted pumpkin shoots ranged from  $0.49 \pm 0.123$  to 0.62 mg/g in polluted soils and from  $0.06 \pm 0.001$  to  $0.15 \pm 0.056$  mg/g in unpolluted soils (Tables 5–6). Elevated nickel concentrations may arise from anthropogenic activities that introduce

metal contaminants into agricultural soils. Atmospheric deposition and soil–plant transfer further facilitate nickel entry into edible plant tissues, increasing the risk of food-chain contamination [65].

Statistical analysis confirmed that soil type had significant effects ( $P < 0.05$ ) on iron, cadmium, arsenic, copper, and nickel concentrations in the shoots of fluted pumpkin, while differences in lead and zinc were not statistically significant (Appendix III). These findings highlight the strong influence of cassava mill effluent contamination on metal accumulation patterns in plant shoots.

The iron content of the fruits of fluted pumpkin grown on untreated cassava mill effluent–polluted soil ranged from 0.00 to  $0.72 \pm 0.555$  mg/g, while fruits from unpolluted soil contained iron in the range of 0.00 to  $0.49 \pm 0.113$  mg/g (Tables 7–8). Iron concentrations were consistently higher in fruits harvested from polluted soils, reflecting enhanced translocation of iron from contaminated soils into reproductive plant tissues. Iron is an essential micronutrient in the human diet; however, excessive intake can be toxic. Toxic doses of iron have been associated with neurological depression, convulsions, respiratory failure, and cardiac arrest, particularly in individuals with impaired iron regulation [66]. Prolonged exposure to excess iron may lead to siderosis of organs such as the liver, pancreas, heart, and endocrine glands, depending on the chemical form of iron ingested [66].

The lead content of the fruits of fluted pumpkin ranged from 0.00 to  $0.61 \pm 0.012$  mg/g in effluent-polluted soil and from 0.00 to  $0.21 \pm 0.091$  mg/g in unpolluted soil (Tables 7–8). Higher lead concentrations in fruits from polluted soils may be attributed to agricultural practices and long-term exposure to cassava mill effluent. Lead is a highly toxic element with no known biological function, and there is no safe threshold for lead exposure [67]. The nervous system is the primary target of lead toxicity, particularly in children, who absorb significantly more lead than adults [68]. Lead interferes with haemoglobin biosynthesis, accumulates in bones and teeth, and may be remobilized during pregnancy, posing risks to the developing fetus [67]. Chronic lead exposure is associated with neurological impairment, hypertension, renal dysfunction, infertility, and adverse pregnancy outcomes [68, 69].

The cadmium content of fluted pumpkin fruits from effluent-polluted soil ranged from 0.00 to  $0.51 \pm 0.012$  mg/g, while fruits from unpolluted soil ranged from 0.00 to  $0.11 \pm 0.012$  mg/g (Tables 7–8). Cadmium levels were higher in fruits grown on polluted soils, indicating continued accumulation from contaminated substrates. Cadmium is a non-essential element with no known biological role and is primarily introduced into the human body through food consumption [67]. It is a cumulative toxicant with a long biological half-life of 16–33 years [70]. Chronic exposure to cadmium has been linked to renal damage, bone demineralization, endocrine disruption, and reproductive toxicity, as well as DNA damage due to its ability to cross the placental barrier [69–71].

The arsenic content of the fruits of fluted pumpkin ranged from 0.00 to  $0.71 \pm 0.102$  mg/g in effluent-polluted soil and from 0.00 to  $0.15 \pm 0.023$  mg/g in unpolluted soil (Tables 7–8). The elevated arsenic concentrations observed in polluted soils may be associated with arsenic-bearing cassava effluent that accumulated in the soil and was subsequently absorbed by the plants. Although leafy vegetables

generally accumulate higher trace metal levels than fruits, arsenic uptake into fruits still poses significant health concerns due to its carcinogenic potential [72, 73].

Zinc concentrations in fruits from effluent-polluted soil ranged from 0.00 to  $0.63 \pm 0.068$  mg/g, whereas fruits from unpolluted soil contained zinc levels between 0.00 and  $0.26 \pm 0.023$  mg/g (Tables 7–8). Zinc is an essential micronutrient required for immune function, brain development, and fetal growth, and its deficiency may be more harmful than excess intake [74;75]. However, excessive zinc exposure may cause gastrointestinal distress and interfere with the metabolism of other essential trace elements. The higher zinc content in fruits from polluted soils suggests increased availability and uptake under contaminated conditions.

The copper content of fluted pumpkin fruits ranged from 0.00 to  $0.55 \pm 0.068$  mg/g in polluted soil and from 0.00 to  $0.17 \pm 0.045$  mg/g in unpolluted soil (Tables 7–8). Copper is an essential element involved in enzymatic reactions, iron metabolism, and plant physiological processes. Comparable studies by Boluwatife et al. [76] and Hamid et al. [77] reported copper concentrations within similar ranges in vegetables grown on contaminated soils. While copper is required for growth and development, excessive accumulation may inhibit plant growth and pose toxicity risks to animals and humans [71].

The nickel content of fluted pumpkin fruits ranged from 0.00 to 0.46 mg/g in effluent-polluted soil and from 0.00 to 0.11 mg/g in unpolluted soil (Tables 7–8). Nickel concentrations were generally higher in polluted soils, reflecting anthropogenic metal inputs. Although nickel is considered an essential trace element, its biological role in humans remains unclear. Excessive nickel exposure has been linked to allergic reactions, organ damage, and increased cancer risk, particularly affecting the liver, kidneys, lungs, and nasal cavity [78; 79].

The one-way analysis of variance (ANOVA) showed that soil type had no significant effect ( $P > 0.05$ ) on the concentrations of iron, lead, cadmium, arsenic, zinc, copper, and nickel in the fruits of fluted pumpkin (Appendix IV). This suggests that, unlike leaves and shoots, metal accumulation in fruits was less influenced by soil contamination under the conditions of this study.

The observed heavy metal concentrations in fluted pumpkin were compared with FAO/WHO permissible limits for metals in food crops (Table 9). Although the concentrations of iron, zinc, copper, and nickel in fruits generally remained within internationally acceptable ranges, lead and cadmium are of particular concern because they have no established safe exposure threshold. The FAO/WHO Joint Expert Committee on Food Additives (JECFA) [68] has emphasized that even low-level, chronic dietary exposure to these metals may result in bioaccumulation and adverse health outcomes, especially among vulnerable populations.

Leaf and shoot samples from cassava mill effluent–polluted soils showed concentrations of lead and cadmium that approached or exceeded recommended limits, indicating a higher potential health risk associated with the consumption of these plant parts. This is particularly relevant in southeastern Nigeria, where fluted pumpkin leaves and shoots are widely consumed as staple vegetables. The

repeated ingestion of contaminated leafy tissues may therefore contribute to long-term exposure, despite individual metal concentrations appearing moderate.

Arsenic and nickel concentrations, although detected, showed limited statistical variation between polluted and unpolluted soils. This suggests restricted translocation or lower bioavailability of these elements under the prevailing soil conditions, yet their presence still warrants concern due to their documented carcinogenic and systemic effects at elevated exposures. Overall, the comparison with FAO/WHO standards highlights the importance of routine food safety assessment in effluent-impacted agricultural systems.

## 5. Conclusion

This study demonstrates that cassava mill effluent discharge significantly influences the bioaccumulation of heavy metals in fluted pumpkin cultivated in Aba, Nigeria, with the magnitude of accumulation varying across plant parts. Leaves and shoots exhibited markedly higher concentrations of iron, lead, cadmium, zinc, and copper in effluent-polluted soils compared to unpolluted controls, while fruits showed comparatively lower accumulation levels.

The findings raise important environmental and public health concerns, particularly given the widespread consumption of fluted pumpkin leaves and shoots. Although some metals remained within FAO/WHO permissible limits, the presence of toxic elements such as lead and cadmium especially in edible leafy tissues suggesting potential long-term dietary risks associated with continued cultivation on untreated effluent-contaminated soils.

The results also indicate the urgent need for regulation and treatment of cassava mill effluents prior to environmental discharge. The adoption of improved waste management practices, soil remediation strategies, and routine monitoring of heavy metals in food crops is essential to safeguard food quality and public health. Promoting sustainable cassava processing methods and enforcing environmental protection policies will be critical for reducing heavy metal contamination in agro-ecosystems and ensuring food safety in rapidly urbanizing regions of Nigeria.

## Declarations

### Ethical approval and consent to participate

*Telfairia occidentalis* seeds used in this study were obtained from a local agricultural market in Aba, Abia State, Nigeria. The plant is a commonly cultivated edible vegetable and is not classified as a protected or endangered species. All experimental procedures involving plant materials complied with institutional, national, and international guidelines for plant research. No specific permits or licenses were required for the cultivation and use of this plant in this study.

## Clinical trial number

Not applicable

## Consent for publication

Not applicable.

## Competing interests

The authors declare no competing interests.

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No funding was received for conducting this study.

## Author Contribution

The data collection, investigation, and preparation of the manuscript's original draft were carried out by Okoye Rosemary. Statistical data analysis were done by Okoye Rosemary. Chinechendo Eze edited and revised the manuscript. The two authors reviewed the final draft of the manuscript.

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## Data Availability

The data that support the findings of this study are included within the paper.

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## Plates

Plate 1 to 2 are available in the Supplementary Files section.

## Supplementary Files

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