Heavy Metals Accumulation In Cabbage, Lettuce And Carrot Irrigated With Wastewater From Nagodi Mining Site In Ghana

G. A. Boamponsem, M. Kumi, I. Debrah

Abstract:- The heavy metal pollution is a major environmental problem especially in mining areas. The study was carried out to quantify heavy metal levels and compare their accumulation in the stems, leaves and roots of *Lactuca sativa* (lettuce), *Brassica oleracea L. var capitata* (cabbage) and *Daucus carrota var sativa* (carrot) irrigated with wastewater from Nagodi mining site. Pot experiment was conducted using surface soil (0-20cm). Differential accumulation and translocation of copper (Cu), lead (Pb), iron (Fe), manganese (Mn) cadmium (Cd) and zinc (Zn) in the root, stem and leaf of vegetables were investigated using atomic absorption spectrophotometer. Cd concentration in the various parts of *D. carrota* was in the range of 0.070 -0.090 mg/Kg. The highest concentration (17.30 mg/Kg) of Mn was found in the stem of *L. sativa.* Fe was highly absorbed (139.6 mg/Kg) by *B. oleracea* roots. The highest concentration (0.221 mg/Kg) of Cu was found in *D. carrota* roots and the highest concentration (35.35 mg/Kg) of Zn was found in the roots of *Brassica.* Cd accumulation in *L. sativa* and *B. oleracea* was below detection limit (< 0.002 mg/Kg). Pb absorbed by the three genotypes was below detection limit (< 0.005 mg/Kg). Though heavy metals were absorbed, their concentrations were below WHO/FAO recommended limits; vegetables cultivated with such wastewater may be considered safe for consumption.

Index Terms:- cabbage, carrot, heavy metals, irrigation, lettuce, mining, wastewater

1 INTRODUCTION

Heavy metals are present in soils as natural components or as a result of human activities. Metal-rich mine tailing, metal smelting, electroplating, gas exhausts, energy and fuel production, intensive agriculture, and sludge dumping are widespread human activities which contaminate soils and aqueous streams with large quantities of toxic metals [1]. Heavy metals are often harmful to humans and other life forms, as they can cause cancer, blindness, loss organ function, severe illness, and death [2]. Heavy metal pollution of aqueous streams, soil, and sediments is a major environmental problem globally. A number of studies from developing countries have reported heavy metals contamination in wastewater and wastewater irrigated soils [3], [4], [5], [6], [7]. Metals-accumulating plants are directly or indirectly responsible for much of the dietary uptake of toxic heavy metals by humans and other animals [8]. While some heavy metals are essential, excessive accumulation in living organisms is toxic. All heavy metals at high concentrations have strong toxic effects and regarded as environmental pollutants [9], [10]. Vegetables such as cabbage (*Brassica juncea*, *Brassica oleracea*) cultivated in wastewater-irrigated soils take up heavy metals in large enough quantities to cause potential health risks to the consumers [11].

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Brassica juncea was chosen as a model plant for rhizofiltration because it accumulates high level of lead and other heavy metals. In addition, several members of the *Brassicaceae* family have been shown to accumulate unusually high concentrations of heavy metals in both shoots and roots [12]. Pollution of groundwater, soil and streams with heavy metals poses environmental problem and serious threat to human health and animals that still needs effective and affordable technological solutions [13]. Ion exchange, chemical and microbiological precipitation methods among others have been developed to remove heavy metals from water, but their use is limited because they are capital, labour and energy intensive [12]. The use of plant in environmental clean-up of such toxic metals can guarantee a greener and cleaner planet for all of us at a cheaper cost. The aim of this work was to measure the concentration of heavy metals in soil and wastewater (from Nagodi mining site) and their translocation in *Lactuca sativa*, *Brassica oleracea L. var capitata* and *Daucus carrota var sativa* and also to evaluate and compare the bioaccumulation of heavy metals in the vegetables grown on soil and wastewater of Nagodi mining site.

2. MATERIALS AND METHODS

2.1 Pot experiment

A pot experiment was conducted using surface soil (0-20cm). The pots were filled with approximately 140 kg of soil sample. The soil sample used for the treatments was taken from Nagodi mining site whilst soil from non-mining area was used as control. The pots filled with polluted soil were irrigated with wastewater from the mining site until the plants matured. Also, the pots with control soil samples were irrigated with tap water of known heavy metal concentration. *Lactuca sativa* and *Brassica oleracea L. var capitata* seeds were nursed three weeks before being transplanted into various pots. *Daucus carrota var sativa* however, was sown at stake.

2.2 Determination of heavy metals in soil and water samples

The concentration of heavy metals and the pH of the soil and water sample were determined before planting. The soil samples were oven dried at 105°C for an hour and grounded to fine particles using mortar and pestle. The grounded particles were sieved using 1 mm sieve. A measured quantity (2.0g) of the soil samples was put into an acid- washed centrifuge bottle (scintillation bottle). Soil samples were digested using 35ml of 0.1M HNO_3. The scintillation bottles were attached to the lid and equilibrated in an end-over-end mechanical shaker and shaked vigorously for sixteen hours. After which the samples were centrifuged at 3000 rpm for five minutes. The supernatant was decanted into the scintillation bottles for analysis. The analysis of the heavy metals was done using the Shimadzu atomic absorption spectrophotometer (model AA6300). The water samples were digested using 2ml of 0.1 M HNO_3 and analyzed using atomic absorption spectrophotometer (model AA6300). The pH of 5.56 of the wastewater sample was determined using the pH meter.

2.3 Preparation and analysis of plant Samples

Lactuca sativa was harvested 76 days, *Brassica oleracea L. var capitata* 90 days and *Daucus carrota var sativa* 78 days after transplanting. The various parts of the plants (leaves, roots and stems) were separated. The samples were wrapped in polyethyene bags and sent to the lab for analysis. The samples were rinsed with de-ionised water for three minutes and oven dried at 105°C for 24 hours. The dried samples were grounded using mortar and pestle and 0.5g of each powdered samples were weighed using the electronic balance. Exactly 30ml of 87% of conc. HNO_3 was used to digest each sample. The heavy metals in the various parts of the plants were analyzed using the Shimadzu atomic absorption spectrophotometer (model AA6300)

3. RESULTS

3.1 Concentration of Heavy Metals in the Soil and Water Samples.

The results indicated that the concentration of Mn, Pb, Fe, Cd and Zn in the wastewater used for the experiment were above the WHO permissible limits. Their concentrations were also higher than the concentrations found in the tap water. The concentration of Cu, Mn, Pb, Fe and Zn in tap water were below the WHO recommended limits. With the exception of Cu, the concentration of Mn, Fe, Pb, Cd and Zn in the soil from Nagodi mining site was higher than the concentration in the Nyankpala series. The Cu concentration found in the Nyankpala series was (0.940 mg/Kg) whiles the concentration found in the soil from the mining site was 0.605 (mg/Kg). The concentrations of copper, manganese, lead, iron, cadmium and zinc are shown in the Table 1 below.

Table 1 Concentration of heavy metals in the various samples used for the experiment

Sample	Heavy Metal concentration					
	Cu	Mn	Pb	Fe	Cd	Zn
Soil from mining site (mg/Kg)	0.605	5.465	1.775	14.076	0.266	6.639
Soil from non-mining site) (mg/Kg)	0.940	0.050	0.040	6.740	<0.002	0.856
Wastewater (mg/L)	0.527	2.107	1.731	15.508	0.267	5.453
Tap Water (mg/L)	0.132	0.068	<0.005	<0.010	0.092	<0.005
WHO Permissible limits (mg/L)	2	0.1	0.05	0.3	0.003	5.0

Where < = below detection limits

3.2 Heavy Metals Content in Vegetables

The mean concentration of cadmium (Cd) was relatively very low (<0.002mg/kg) in various parts of *Brassica oleracea L. var capitata* and *Lactuca sativa*. However, cadmium was accumulated in the various parts of *Daucus carrota var sativa* irrigated with wastewater and tap water. The concentration of Pb in the root, stem and leaf of the vegetables was below the detection limit (<0.005). The highest concentration of Fe (156.2 mg/Kg) was found in the roots of *Brassica* irrigated with tap water. Fe adsorption in the stem, root and leaf of *Daucus carrota var sativa* irrigated with wastewater and tap water was below the detection limit (<0.010 mg/Kg). The highest concentration of Zn was recorded in *Brassica* roots irrigated with tap water. The lowest concentration of Zn was below detection limit (< 0.005 mg/Kg) and was found in *Daucus carrota var sativa* (irrigated with wastewater and tap water). *Lactuca sativa* stem (irrigated with wastewater) had the highest concentration of Mn accumulation (17.30 mg/Kg). The concentration of Cu in root, stem and leaf of the three vegetables irrigated with wastewater and tap water were below 0.30 mg/Kg. The highest concentration of Cu (0.22 mg/Kg) was found in *Daucus carrota var sativa* roots. Different vegetables used for the experiment and their metal accumulation are shown in table 2 and table 3.

Table 2 Mean concentration of heavy metals in the root, stem and leaf of the Brassica oleracea L. var capitata, Lactuca sativa and Daucus carrota var sativa irrigated with wastewater

Vegetables	Heavy Metal concentration (mg/Kg)					
	Cu	Mn	Pb	Fe	Cd	Zn
BLww	0.020	1.383	<0.005	2.215	<0.002	1.641
BSww	0.040	0.870	<0.005	2.304	<0.002	1.554
BRww	0.139	9.692	<0.005	139.6	<0.002	1.357
LLww	0.145	4.801	<0.005	15.04	<0.002	1.853
LSww	0.172	17.30	<0.005	7.311	<0.002	1.325
LRww	0.163	3.222	<0.005	10.94	<0.002	2.012
DLww	0.143	0.068	<0.005	<0.010	0.071	<0.005
DSww	0.092	0.056	<0.005	<0.010	0.082	<0.005
DRww	0.221	0.071	<0.005	<0.010	0.058	<0.005

ww: wastewater; **BLww**:*Brassica oleracea* leaves; **BSww**: *Brassica oleracea* stems; **BRww**: *Brassica oleracea* roots; **LLww**: *Lactuca sativa* leaves; **LSww**: *Lactuca sativa* stems; **LRww**: *Lactuca sativa* roots; **DLww**:*Daucus carrota var sativa* leaves; **DSww**:Daucus carrota var sativa stems; **DRww**: *Daucus carrota var sativa* roots. **Where** < = below detection limits

Table 3 mean concentration of heavy metals in the root, stem and leaf of the Brassica oleracea L. var capitata, Lactuca sativa and Daucus carrota var sativa irrigated with tap water

Vegetable	Heavy Metal concentration (mg/Kg)					
	Cu	Mn	Pb	Fe	Cd	Zn
BLtw	0.030	1.055	<0.005	3.391	<0.002	0.878
BStw	0.058	0.512	<0.005	2.153	<0.002	8.377
BRtw	0.073	9.431	<0.005	156.2	<0.002	35.35
LLtw	0.129	9.401	<0.005	12.25	<0.002	7.000
LStw	0.071	4.242	<0.005	10.51	<0.002	2.556
LRtw	0.036	7.771	<0.005	13.06	<0.002	2.690
DLtw	0.105	0.084	<0.005	<0.010	0.074	<0.005
DStw	0.103	0.070	<0.005	<0.010	0.071	<0.005
DRtw	0.089	0.070	<0.005	<0.010	0.090	<0.005

tw: tap water (unpolluted) ;***BLtw*** :*Brassica oleracea* leaves; ***BStw***: *Brassica oleracea* stems; ***BRtw***: *Brassica oleracea* roots; ***LLtw***: *Lactuca sativa* leaves; ***LStw***: *Lactuca sativa* stems; ***LRtw***: *Lactuca sativa* roots; ***DLtw***: *Daucus carrota var sativa* leaves; **DStw**: *Daucus carrota var sativa* stems; ***DRtw***: *Daucus carrota var sativa* roots. **Where** < = below detection limits.

Table 4 indicates Pd concentration which was below detection limit in the three vegetables. Cd concentration was also below detection limit in *Brassica* and *Lactuca sativa.* Fe and Zn were also below detection limits in *Daucus carrota*. *Lactuca sativa* irrigated with tap water absorbed the highest concentration of Zn. *Brassica* irrigated with tap water absorbed the highest concentration (5.391 mg/Kg) of Fe and it was followed by *Brassica* irrigated with wastewater (4.803 mg/Kg).

The highest mean concentration of Mn (7.787 mg/Kg) was *Lactuca sativa* irrigated with wastewater and the lowest concentration (0.065 mg/Kg) was *Daucus carrota* irrigated with wastewater. The highest mean concentration of Cu (0.162 mg/Kg) was *Lactuca sativa* irrigated with wastewater and this was followed by *Daucus carrota* irrigated with wastewater (0.152 mg/Kg).The lowest concentration of Cu was *Brassica.*

Table 4 The mean and standard deviation of *Brassica oleracea L. var capitata* (cabbage), *Lactuca sativa* (lettuce) and *Daucus carrota var sativa* (carrot) irrigated with wastewater and tap water.

Vegetable	Heavy Metal concentration (mg/ Kg)					
	Cu	Mn	Pb	Fe	Cd	Zn
Bww	0.066 (±0.06)	3.981 (±4.95)	BDL	4.803 (±79.29)	BDL	1.517 (±0.15)
Btw	0.053 (±0.02)	3.666 (±5.00)	BDL	5.391 (±88.58)	BDL	1.486 (±18.13)
Lww	0.160 (±0.01)	1.313 (±6.25)	BDL	1.199 (±3.11)	BDL	1.779 (±0.31)
Ltw	0.078 (±0.05)	7.787 (±1.95)	BDL	1.203 (±1.05)	BDL	5.125 (±2.26)
Dww	0.152 (±0.65)	0.065 (±0.01)	BDL	BDL	0.070 (±0.01	BDL
Dtw	0.099 (±0.01)	0.074 (±0.02)	BDL	BDL	0.078 (±0.10	BDL

BDL = below detection limits, ± sandard deviation

ww: wastewater; tw: tap water; Bww: Brassica oleracea irrigated with wastewater; Btw: Brassica oleracea irrigated with tap water; Lww: Lactuca sativa irrigated with wastewater; Ltw: Lactuca sativa irrigated with tap water; Dww: Daucus carrota irrigated with wastewater; Dtw; Daucus carrota irrigated with tap water

3.3 Permissible Guidelines for Heavy Metals in Vegetables

Permissible guidelines are standard values set by Food and Agriculture Organization and World Health Organization (FAO/WHO) and other authorities to monitor levels of heavy metals in vegetables**.** The various guideline values illustrated in table 5.

Table 5 The Maximum Permissible Concentrations (mg/Kg) of Copper, Lead, Iron, Manganese and Zinc in Vegetables Safe for Consumption.

	Cu	Mn	Pb	Fe	Cd	Zn
FAO/WHO	73.30a	500.00a	0.30a	425.50a	0.20a	99.40a
Others	73.30b	500.00c	_	425.50b	_	_

a = [14], b = [15], c = [15]

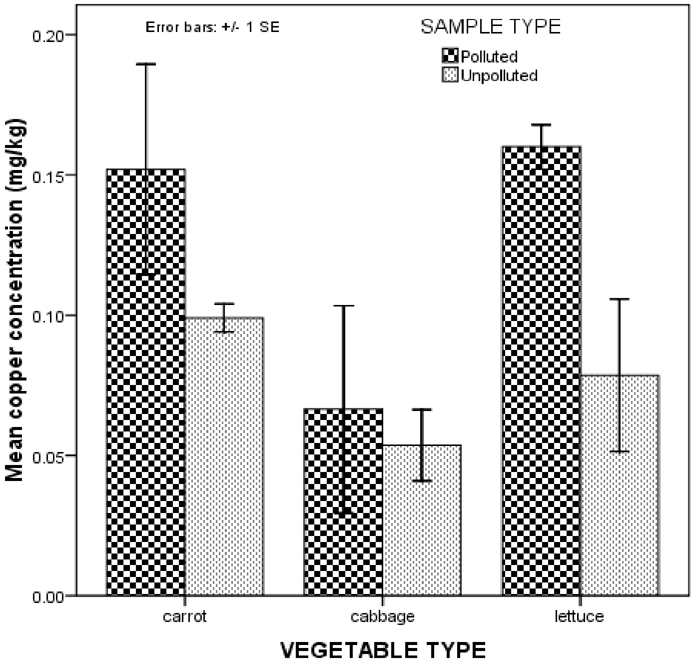

Fig. 1: mean concentration of Cu in the *Brassica oleracea L. var capitata* (cabbage), *Daucus carrota var sativa* (carrot) and *Lactuca sativa* (lettuce) vegetables irrigated with wastewater (polluted) and tap water (unpolluted)

Fig.1 indicated that there were significant differences in Cu concentration in the three vegetables irrigated with wastewater (polluted) and tap water (unpolluted). Vegetables irrigated with wastewater have shown the higher concentration of Cu than those irrigated with tap water. The order of Cu accumulation of the three vegetables irrigated with wastewater, was *Lactuca* sativa (0.160 mg/Kg) > *Daucus carrota var sativa* (0.152 mg/Kg) > *Brassica oleracea L. var capitata* (0.066mg/Kg).

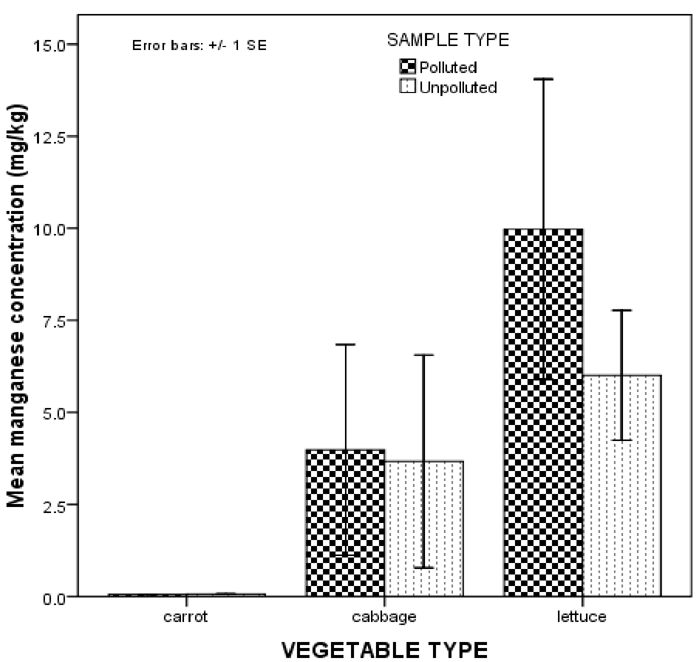

Fig. 2: mean concentration of Mn in *Brassica oleracea L. var capitata* (cabbage), *Daucus carrota var sativa* (carrot) and *Lactuca sativa* (lettuce) irrigated with wastewater (polluted) and tap water (unpolluted)

Fig.3 above indicated that there were significant differences between the vegetables irrigated with wastewater and tap water. The highest mean concentration of Mn was *Lactuca sativa* (lettuce) and this was followed by *Brassica* and *Daucus carrota*. Vegetables irrigated with wastewater accumulated Mn which was higher than those irrigated with wastewater. The lowest concentration Mn was *Daucus carrota var sativa* (carrot).

4. DISCUSSION

The heavy metals accumulation and translocation potential varied from metal to metal and from plant to plant and did not follow any particular pattern. Genotypic effect, environmental effect and their interaction effects highly affect heavy metals uptake in crop genotypes [17], [18], [19]. Moreover, heavy metals in soils occur in complicated forms because of their association with a number of physicochemical forms that in turn influence their availability [20]. Plants take up heavy metals from the soil through different reactions such as adsorption, ionic exchange, redox reaction, precipitation, dissolution among others [21]. The relatively low concentration of Cd accumulated in *Brassica oleracea L. var capitata* and *Lactuca sativa* (table 2) may be ascribed to the presence of Zn in these vegetables. Some researchers found that the presence of Zn can inhibits Cd adsorption and thereby cause low Cd accumulation in plants [22], [4]. The results in table 2 indicated that *Brassica oleracea L. var capitata* and *Lactuca sativa* were able to accumulate a certain amount of Zn. Cd and Zn might be considered chemically similar elements because they have similar ionic structure and electronegativities and may influence each other in plant uptake and accumulation, but they play quite different roles in the plant metabolism. Zinc is a micronutrient whereas Cd is toxic and does not play any role in plants [23]. However, they have different ionic radii (Zn^{2+} = 0.074 nm, Cd^{2+} = 0.0979 nm); this difference may play role in the plant selectivity for zinc [24]. It was also revealed that mean concentration of Cd absorbed in the parts of *Daucus carota var sativa* was higher than *Brassica oleracea L. var capitata* and *Lactuca sativa*. This might be as a result of the absence of Zn since Zn absorbed by the vegetable was below detection limit (<0.005mg/kg) (table 2 and table 4). Cd and Zn are elements having similar geochemical and environmental properties; their chemical similarity can lead to interaction between the two metals during plant uptake, transport or accumulation in the various parts of plants [25]. Antagonistic effects of Cd and Zn have been reported by [26]. Therefore, it is generally accepted that Zn status in the soil and plant plays an important role in Cd accumulation in crop plants. Moreover, the low accumulation of Cd found in *Brassica oleracea L. var capitata* and *Lactuca sativa* could also be as a result of the Fe found in the vegetables. Iron concentration can also reduce the uptake of Cd. [27] also reported Fe concentration reduced the uptake of metals particularly Cd. The order of Zn accumulation in *Brassica oleracea L. var capitata* is stem > leaf >root and *Lactuca sativa* root > leaf > stem. It can be noted from table 3 that the mean concentration of Zn in the vegetables irrigated with tap water was a higher than the treatments with the *Brassica* root (the control/unpolluted) having the highest (35.35mg/kg). Zn is a micronutrient essential for plant metabolism thus the vegetables absorbed it for physiological functions as evident in faster growth rate observed in the control than those grown in the soil from mining site irrigated with wastewater. It might also be as a result of extremely low accumulation of Cd (<0.002 mg/kg). The uptake of Fe in *Daucus carota var sativa* was below detection limits (<0.010mg/kg). The highest concentration was found in the roots of *Brassica* followed by *Lactuca sativa*. It could also be realized that the *Brassica* root (control) accumulate the highest concentration of Fe (156.2 mg/kg). The high concentration of Fe accumulated in the roots of *Brassica* may be attributed to the microbial consortium in the roots which excrete organic acids that facilitate the absorption and accumulation of Fe in the roots. In support of this, [28] reported that some microorganisms excrete organic compounds which increase bioavailability and enhance root absorption of essential metals including Fe. Copper is an essential micronutrient known to play important role in plant development. In the study Cu accumulated in various parts of the crops. The order of copper accumulation in *Brassica oleracea L. var capitata* is root > stem >leaf; *Daucus carota var sativa* is root >leaf >stem and *Lactuca sativa* stem >root >leaf. The mean concentration of copper in the vegetables was far below the permissible limit recommended by FAO in vegetables (73.3mg/kg) (table 5). The lowest concentration of Mn was found in *Daucus carota var sativa*. The order of Mn absorption is *Lactuca sativa >Brassica oleracea L. var capitata* > *Daucus carota var sativa* (fig.3). The order of accumulation in *Lactuca sativa* was stem > leaf >root, *Brassica oleracea L. var capitata* was root > leaf > stem and *Daucus carota var sativa* is root >stem =leaf (fig. 5). The stem of *Lactuca sativa* had the highest concentration of Mn (17.30 mg/kg) compared to other parts of the plant. All the concentrations are below the FAO/WHO recommended international standard (Table 2). Lead was the least heavy metal absorbed by any of the crops used in the experiment. The mean concentration of Pb accumulation was below detection limit (< 0.005mg/kg). The soil pH is an important factor that determines the uptake of Pb. The pH of the soil (from the mining site/polluted) used for the experiment was 5.48 which is mildly acidic. The more acidic the soil, the greater the mobilization of Pb and thus increase the uptake. Some researchers also reported that at lower pH, lead in the soil has greater potential to be uptake and translocated by plants [29]. The availability of Pb in the soil has the potential to be absorbed and translocated by plants growing in such soils. However, Pb is difficult to be translocated by plants. In support of this, [21] noted that Pb is heavily adsorbed by particles of sediment and thus it is difficult to be translocated. The limiting step for Pb accumulation is the long distance translocation from roots to shoots [30].

5. CONCLUSIONS

Lead was the least element absorbed by the vegetables investigated; Zn and Fe accumulation in *Daucus carota var sativa* were below detection limit, Cd accumulation in *Brassica oleracea L. var capitata* and *Lactuca sativa* below detection limits (< 0.002 mg/Kg). In general, the mean concentrations of heavy metals accumulated by these genotypes were below WHO/FAO recommended limits (table 5) for vegetables and may be considered safe for consumption.

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