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Research article

Health Risk Assessment of Heavy Metals Associated with *Terminalia catappa* Fruit Consumption Obtained from an Automobile Workshop Cluster in Nsukka, Nigeria

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Abstract

The indiscriminate disposal of wastes generated from automobile workshops has contributed immensely to the accumulation of heavy metals within the immediate environment. Food security and human health are threatened as edible plants and fruits take up these metals. This study investigated the health risk assessment associated with *Terminalia catappa* fruit consumption. Soil and *Terminalia catappa* plant parts (roots, stems, shoots and fruit) from Nsukka automobile workshop were analyzed for As, Cr, Ni, Cu. Pb, Zn, Cd, and Fe. This was done using an atomic absorption spectrometer after acid digestion. The average concentration of As, Cr, Ni, Cu. Pb, Zn, Cd, and Fe in the fruit were 1.09±0.49, 1.43±0.74, 1.08±0.45, 19.31±6.32, 4.21±1.73, 11.23±1.45, 1.87±0.17 and 28.35±4.22 mg/kg, respectively. Arsenic and cadmium had a relatively higher BCF (As - 0.66, Cd - 1.15), TF (As - 0.92 and Cd - 0.83) and BAF (As - 0.47 and Cd - 0.45) when compared to other investigated metals. The HQ obtained for Cd was the highest (0.895), while the THI was 1.869. The heavy metal concentration in fruit exceeded the acceptable permissible limits stipulated by USEPA, WHO and FAO. From the risk assessment, it was concluded that cadmium was the major contributing factor associated with developing health hazards and carcinogenic risk. Therefore, it is fitting to notify the target population who consume tropical almonds from Nsukka automobile workshop how unsafe eating the fruit can be.

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1. Introduction

Heavy metals occur naturally in low concentrations and with a density of 5 g/cm^3 and above. They can be discovered within the earth's crust in a bound or free form. Carbonate, sulfate, oxide, or silicate rocks are said to be their bound form while they also occur in their metallic or elemental form, considered to be their free form [1]. A few of these heavy metals perform some crucial biological roles, and their absence can be detrimental to those functions. Examples of heavy metals such as these, which act in trace or minute amounts, include iron (Fe), selenium (Sn), copper (Cu) and zinc (Zn). However, the accumulation of these metals can also become harmful to the biotic and abiotic environments [2]. They accumulate because unlike organic pollutants, they are not readily degraded. The contamination of food by heavy metals has become a threat to food security and safety. Foods can be exposed to heavy metals in different ways. Fruits and vegetables may be exposed when they are grown in contaminated areas and soil, or are irrigated with water that has been contaminated with industrial wastes. In the course of harvesting and storage, and on the verge of sale, such produce may be further contaminated [3]. Reports have also been made regarding heavy metals accumulating within the edible parts of fruits [4].

There has been an increase in awareness of the benefits and health properties of antioxidants. Since the dawn of these perceptions, interest in fruits rich in antioxidants has increased [5]. These fruits are sources of vitamins, fiber and minerals and are consumed in various forms. *Terminalia catappa* is a widely grown fruit in Africa and in the world at large. It has been cultivated in Africa for wood (fuel or cooking fire), fruits, and fodder [6]. *Terminalia catappa* has also been cultivated in Africa as an ornamental and shading plant. *Terminalia catappa* plants are also found around and within mechanic villages or automobile workshops. They have been the workers' source of shade during working hours and source of fruit. The fruits of these plants in these contaminated sites accumulates heavy metals [7]. The continuous consumption of fruits grown in polluted sites can lead to bioaccumulation of heavy metals in man, which can be harmful. These heavy metals are needed in minute amounts for some important biological processes and signalling, but in excess amounts, they can become toxic and detrimental. Some heavy metals such as lead (Pb), chromium (Cr), arsenic (Ar), copper (Cu) and cadmium (Cd) have been associated with cancer, neurotoxicity, hepatotoxicity, neo-natal mortality and renal toxicity [8], threatening mankind. This makes it pertinent to evaluate human health risks associated with these fruits grown around automobile workshops, which are also known as mechanic villages.

Food security and health have been a quest to conquer due to the population boom and environmental pollution. As a result, it has become apt for foods to be evaluated in relation to the risks they pose to human health. Risk assessment and evaluation is determining the possibility that adverse effects will occur when exposed to a substance over a time span [9]. These risks are evaluated according to procedures stipulated by the United States environmental agency (USEPA). They involve determining the estimated daily intake (EDI), determining the carcinogenic risk, determining the hazard quotient (HQ) and hazard index (HI) as well as bioaccumulation factor [9]. The estimated daily intake is the probable quantity the model consumes daily, which varies among adults and children [10]. The toxic hazard quotient (THQ) is expressed as a ratio between the probable average daily exposure to a substance and the level at which there is no appreciable risk of adverse health effects over a period of lifetime [11]; it is the ratio of exposure to reference dose. When the quotient obtained is greater than one (THQ >1), it suggests that adverse effects are probable, while when it is less than one (THQ < 1), there are no adverse effects to health expected [10]. The carcinogenic risk is seen as the probability that a person will develop cancer by consuming a particular substance over a period of lifetime. This is usually estimated using the incremental lifetime cancer risk (ILCR) determined by daily dose exposure to the substance for the period of a lifetime [12]. The USEPA stipulated that the ILCR of one in a million (1×10^{-6}) suggests that when one million samples are exposed to this substance and one case of cancer results, it is too negligible to be considered as a cancer risk. The USEPA suggested that the acceptable range for a cancer risk benchmark for investigation should be within the range of one in ten thousand (1×10^{-4}) while ILCR of one in a thousand (1×10^{-3}) calls for public health concern [11]. This study investigated and quantified the concentration of heavy metals in *Terminalia catappa* (tropical almond or black almond and locally called "fruit" in Eastern Nigeria) obtained from an automobile workshop/ mechanic village and its probable risks on human health using the risk assessment models.

There are many research studies on *Terminalia catappa* leaves and fruit shells such as the reports on the biosorption of lead ions using *Terminalia catappa* leaves [12] and the use of *Terminalia catappa* fruit shell as biosorbent for the removal of Pb (II), Cd (II) and Cu (II) ion in liquid waste [13]. However, no work has shown the health risks associated with the consumption of its fruit, which is the pivotal focus of this research.

2. Materials and Methods

2.1 Sample collection

Terminalia catappa roots, stems, shoot and fruit samples were collected from an automobile workshop cluster in Nsukka. The roots were collected at a depth of 10-20 cm. These samples were collected using a sterilized knife. The knife was also sterilized (using alcohol) after each sample collection to avoid cross-contamination. Control sample was collected 500 m away from the workshop cluster. The *Terminalia catappa* samples were washed, cut and stored until the investigation commenced. The sampling was done during the rainy season in Nigeria. Soil samples from each point were collected in duplicate at the sub-surface level at 10 -20 cm depths using a soil auger and transported to the laboratory in a sterile polyethylene bag. The soil samples were thoroughly mixed to obtain a representative sample, air dried, crushed and sieved with 2 mm mesh before wet digestion.

2.2 Sample digestion

The plant samples were washed and submerged into 10% HNO_3 as described by Protano *et al*. [14]. The samples were dried, ground and sieved using a 200 µm pore-sized sieve. A nitric-perchloric acid digestion was carried out according to the method of the Association of Official Analytical Chemists [15]. The digestion process involved adding 2 g of the obtained sieved fine particles into a 250 ml beaker containing 20 ml of HNO_3. This was boiled for 45 min to oxidize the organic matter and then cooled. After cooling, 5 ml of 70% $HClO_4$ was added to the mixture and boiled again until white fumes were given off. It was cooled and then 20 ml of distilled water was added, and boiled again to release the fumes completely. It was digested on a hot plate in the fume cupboard to allow for the evaporation of HCl until the solution was clear. The solution was cooled and filtered before making it up to 100 ml with deionized water. The digested sample was analysed for arsenic (As), lead (Pb), chromium (Cr), cadmium (Cd), iron (Fe), nickel (Ni), copper (Cu), and zinc (Zn) using Atomic Absorption Spectrophotometer (AAS). The data obtained were expressed as Mean ± S.D and the level of significance was set at p <0.005.

2.3 Heavy metal determination

The heavy metals were detected with the use of AAS and measured in ppm, which employed the principle of Beer Lamberts law. The precision and accuracy of the atomic absorption spectrophotometer were set with a metal detection minimum at 0.0001 using the spike recovery method according to the International Union of Pure and Applied Chemistry [16]. A quantity of spiked metal was used to determine the percentage recovery of each metal as seen in equation 1 described by Burns *et al*. [17].

$$\%\, recovery = \frac{Concentration\ of\ spiked\ sample - Concentration\ of\ Unspiked\ sample}{Concentration\ of\ analyte\ added\ (spike\ with)} \times 100 \quad (1)$$

2.4 Heavy metal pollution characterization

The maximum permissible heavy metal concentration in soil and plants are shown in Table 1. The maximum threshold heavy metal concentration (mg/kg) in soil was designated by the World Health Organization (WHO) and the Food and Agricultural Organization (FAO) whereas the maximum allowed concentration limits of some toxic metals in soil and fruits (mg/kg) was designated by WHO [18, 19].

Table 1. Maximum allowable concentration in soil and plants [18, 19]

Heavy Metals	Maximum limits allowed in soil (mg/kg)	Maximum allowed limits in the plant (mg/kg)
Arsenic (As)	20	0.02 (FAO)
Chromium (Cr)	100	0.85 (WHO)
Nickel (Ni)	80	0.20 (EU)
Copper (Cu)	30	0.20 (WHO)
Lead (Pb)	100	0.01 (WHO)
Zinc (Zn)	300	5.0 (WHO)
Cadmium (Cd)	3	0.10 (WHO)

2.5 Phytoremediation properties

2.5.1 Biological concentration factor

The bioconcentration factor (BCF) was calculated by dividing the heavy metal concentration in plant roots by the heavy metal concentration in the soil, which can be seen in the equation 2 as shown below [20].

$$BCF = \frac{HMR}{HMS} \quad (2)$$

Where; BCF = Bioconcentration factor
HMR = Heavy metal concentration in roots
HMS = Heavy metal concentration in soil

2.5.2 The translocation factor

The translocation factor was determined as the ratio of heavy metals in plant shoots to that in the roots [20] and this can be seen in the equation 3 below.

$$TF = \frac{HMSh}{HMR} \quad (3)$$

Where; TF = Translocation factor

HMSh = Heavy metal concentration in the shoots of *Terminalia catappa* (tropical almond)
HMR = Heavy metal concentration in the roots

2.5.3 Estimation of bioaccumulation factor (BAF)

The rate at which heavy metals are transferred from the soil to the plant was determined by dividing the concentration of the contaminant heavy metals in *Terminalia catappa* by the total contaminant heavy metal concentration in the soil. This index of soil to plant transfer or intake of metals from the soil through *Terminalia catappa* can also be evaluated using the following equation (equation 4) described by Olowoyo *et al* [21].

$$BAF = \frac{CHMTC}{CHMS} \tag{4}$$

Where; BAF represents the transfer factor of fruit
CHMTC = Concentration of heavy metal in *Terminalia catappa*, mg/kg fresh weight
CHMS = Concentration of heavy metal present in soil, mg/kg dry weight
BAF > 1 indicates that *Terminalia catappa* are enriched in elements from the soil (bioaccumulation)
BAF < 1 means that *Terminalia catappa* excluded the element from soil (excluder)

2.6 Non-carcinogenic health risk assessment

2.6.1 Estimation of the daily metal intake (EDIM)

This is determined by the specific intake of each contaminant with reference to the acceptable, tolerable limits. This was calculated using the following formula (equation 5) expressed in mg/person/day as per Meseret *et al*. [22]

$$EDIM = \frac{CHMTC\ \times DIM}{BW} \tag{5}$$

Where; EDIM represents the estimated daily intake or average daily dose (mg/kg body weight) of the metal
DIM is the daily intake of *Terminalia catappa* of the target population (g/person/day WHO)
CHMTC is the heavy metal concentration in the *Terminalia catappa* (mg/kg)
WB represents the average body weight of the target population (kg).

2.6.2 Toxic hazard quotient (THQ)

This is used to denote the risks associated with exposure to non-carcinogenic substances. It is the ratio between exposure and oral reference dose (RFD) in mg/kg/day and if it is above one, then there is a probability of the relevant substance causing adverse effects. The use of THQ to estimate risk was provided in USEPA region 3 risk-based concentration, as shown in Table 2 with the calculations shown in equation 6 [23]. This does not provide a quantifiable probability that the exposed population is suffering from adverse health due to the substance but gives information on risk level due to the same exposure [24]. The oral reference dose (RFD) is the stipulated daily oral dose of a substance that an individual or a population can be exposed to over the period of a lifetime without facing the risk of developing cancer or suffering from deleterious effects [25].

Table 2. Romanian guidelines on toxic metals level permitted in soil for pollution assessment in mg/kg [26]

Metals	European median soil	World median	NV*	ALS*	ALLS*	ITS*	ITLS*
Arsenic (As)	7.03	6	5	15	25	25	50
Chromium (Cr)	60	70	30	100	300	300	600
Nickel (Ni)	18	50	20	75	200	150	500
Copper (Cu)	13	30	20	100	250	200	500
Lead (Pb)	22.6	35	20	50	250	100	1000
Zinc (Zn)	52	90	100	300	700	600	1500
Cadmium (Cd)	0.145	0.35	1	3	5	5	10
Iron (Fe)	-	-	-	-	-	-	-

*ALS - Alert level for the sensitive area, ALLS - Alert level for less sensitive area, ITS - Intervention for the sensitive area, ITLS - Intervention for less sensitive areas, and NV - Normal value

$$THQ = \frac{Concentration\ of\ metals\ in\ Terminalia\ catappa \times Daily\ intake\ of\ Terminalia\ catappa}{RFD\ \times Average\ body\ weight}$$

$$THQ = \frac{ADD}{RFD} \qquad (6)$$

When the THQ is less than one (THQ < 1), the substance poses no non-carcinogenic risk to the consumers, while when it is above one (THQ > 1), the consumers are threatened with a non-carcinogenic risk of the metal.

2.6.3 Hazard index (THI)

The toxic hazard index was determined to estimate the overall risk of exposure to the total heavy metals present in the sample (*Terminalia catappa*). It was developed by USEPA and is calculated by aggregating the individual THQ from all the heavy metals examined, as seen in the next equation (equation 7). Here again, if the THI is less than one (< 1) the consumers of the fruit are considered safe and acceptable, while when it is equal to or greater than one (≥ 1) the fruit is considered unsafe and risk management measures should be taken for consumption.

$$\text{THI} = \sum_{i=1}^{n} \text{THQ} \qquad (7)$$

Where; n stands for the concentration of heavy metals present.
i stands for the individual metal.
Toxic hazard index (THI) = $THQ_{Zn} + THQ_{Cr} + THQ_{Fe} + THQ_{Pb} + THQ_{Cd} + THQ_{As+} THQ_{Hg}$

2.7 Carcinogenic health risk assessment

2.7.1 Incremental lifetime carcinogenic risk (ILCR)

The slope factor is the toxicity data used to evaluate the cancer risk associated with exposure to a particular substance. It is a feasible upper bound estimate of lifetime exposure to a certain concentration potentially carcinogenic substance that can lead to cancer [25] and is expressed in units of (mg/kg/day). The slope factors indicate the carcinogenic potency and its relationship with how a substance's daily dose can lead to cancer [25]. The ingestion reference dose (RfDing)and carcinogenic slope factors (CSF) for heavy metals are shown in Table 3. The lifetime probability of cancer can be calculated by the equation below (equation 8). Cancer risks in the range of 1.0×10^{-6} to 1.0×10^{-4} are within the acceptable limit [27]. This limit is usually examined after the summation of the obtained ILCR (incremental lifetime cancer risk) for the investigated heavy metals that are carcinogenic. The investigated carcinogenic metals are always more than 1.

Table 3. The ingestion reference dose (RfD) and the carcinogenic slope factor of specific (CSF) heavy metals [10, 28, 29]

Heavy Metals	Reference Dose (RfDing) (mg/person/day)	Carcinogenic Slope Factor (CSF) (mg/kg/day)
Arsenic (As)	0.0050	1.5000
Chromium (Cr)	1.500	0.5000
Nickel (Ni)	0.0200	1.7000
Copper (Cu)	0.0400	0.0020
Lead (Pb)	0.0035	0.0085
Zinc (Zn)	0.3000	0.0000
Cadmium (Cd)	0.001	0.38
Iron (Fe)	0.70	0.000

$$\text{ILCR} = \text{Estimated Daily Intake (mg/kg/day) x Carcinogenic Slope Factor (mg/kg/day)} \quad (8)$$

2.8 Statistical analysis

The data obtained were analysed using IBM Statistical Product and Service Solution (SPSS) version 20 and Microsoft excel 2013. The results were expressed as mean ± standard deviation (SD). One-way analysis of variance (ANOVA) was carried out as $p<0.05$ considered statistically significant. Duncan's multiple range test (DMRT) was used to compare mean values of test groups and control as well as differences within group means of the various test groups.

3. Results and Discussion

The increases in the heavy metal concentrations in both soil and food have been attributed to human activities in nature and their quest to improve their standard of living [29]. The major concern here is the possible risks posed by automobile servicers and workshops. A majority of the waste generated from these workshops and servicing systems contain heavy metals that are incorrectly disposed into the soil.

Table 4 stipulates that the heavy metal concentration in the soil samples isolated in this study showed that the control site had lower levels of heavy metal concentration compared to the samples obtained from the automobile workshop. Iron recorded 1612.19±5.44 mg/kg as the highest concentration in the samples obtained from the workshop. Although all the heavy metals investigated, except for iron (Fe) copper (Cu) and cadmium (Cd), were below the maximum allowed limit (or concentration) in the soil samples. The order of concentration in the soil was as follows: Fe > Zn > Cu > Pb > Cr > Ni > Cd > As. This can be accredited to the wastes generated from the practices (automobile servicing and repairs) that were ongoing within the environment. This result

Table 4. Heavy metal concentrations in soil sample (mg/kg)

Heavy Metals	**Maximum limits (mg/kg)**	**Sample 1 (Control)**	**Sample 2**
Arsenic (As)	20 (WHO)	0.7 ±0.12[a]	2.31 ±0.52 [a]
Chromium (Cr)	100 (WHO)	6.44 ±1.54[b]	8.01 ± 0.22 [b]
Nickel (Ni)	80 (WHO)	4.36 ±1.22 [a]	7.66 ±0.78 [b]
Copper (Cu)	30 (WHO)	96.76 ±6.87 [cd]	121.14 ±7.52 [d]
Lead (Pb)	100 (WHO)	6.35 ±3.36 [b]	22.42 ±3.41 [bc]
Zinc (Zn)	300 (WHO)	153.94 ± 4.14 [d]	278.66 ±3.66 [d]
Cadmium (Cd)	3 (WHO)	2.23 ±0.44 [a]	4.11 ±0.23 [a]
Iron (Fe)	400 (WHO)	1284.17 ±6.03 [e]	1612.19 ±5.44 [e]

is also in tandem with Ameh *et al*. [30], who also observed an elevated level of heavy metals in automobile and generator workshops compared to the control. The percentage concentrations of the heavy metals investigated in the soil when compared to the control were as follows: As (55%)> Pb (53%)> Cd (29%) > Zn (28%) > Ni (27%) > Fe (11%)> Cr (10.86%) > Cu (1.84%). From the percentage composition of these metals, it can be deduced that there was an increase in the composition of carcinogenic metals when compared to the control, which over time could become detrimental to the soil and by extension to the human population. These metals were below target values or permissible limits in the soil according to WHO 1996 except for cadmium (4.11±0.23 mg/kg) which exceeded the permissible limit of 3 mg/kg, and iron which had a concentration of 1612.19±5.44 mg/kg. This may have been due to the panel beating and painting of automobile parts that was, and still is, a prominent activity here. Since some automobile parts are made of PVCs (plastics) containing cadmium and some cadmium-based paints [31], this type of automobile servicing releases more cadmium into the environment, thereby increasing the cadmium concentration within the topsoil. According to the Romanian guidelines on toxic metal levels permitted in soil for pollution assessment, the cadmium content in the soil reached the alert level in the sensitive area (Romanian reference values for trace elements in soil). The metals copper and zinc, which had values of 121.14±7.52 mg/kg and 278.66±3.66 mg/kg, also reached the alert level for soil within the sensitive area and the alert level for soils within less sensitive areas, respectively (Romanian reference values for trace elements in soil). Iron increased beyond its permissible limit (400 mg/kg) set by WHO [18] in both the control site and the workshop site. The obtained result (1612.19±5.44 mg/kg) was in tandem with Adewole and Uchegu [32], who investigated the properties of soils within the vicinity of automobile workshops. The increase observed could be an impact of the servicing part of automobiles that involves metal constructions such as iron filings and bending, the lubrication of rusting parts and the disposal of spent oil and lubricants. The high content observed in the control may have been due to the automobile artisans disposing of their wastes aimlessly or unsystematically [33].

Table 5 shows the heavy metal concentration in the plant tissues (roots, stems, shoots and fruit). Of the investigated metals in the roots, iron (Fe) had the highest heavy metal concentration, 38.46±6.47 mg/kg, while arsenic came in at 1.52±0.22 mg/kg, the lowest concentration. The magnitude of occurrence of these metals was in decreasing order as follows: Fe > Cu > Zn > Pb > Cd > Cr > Ni > As. The heavy metal concentration analysed within the shoots of the plant also had iron (Fe) as the heavy metal with the highest concentration (34.93±7.38 mg/kg) and nickel (Ni) with the lowest concentration (1.21±0.12mg/kg). The disposition of these metals in the shoots was Fe > Cu > Zn > Pb > Cd > As > Cr > Ni. In the stems of *Terminalia catappa*, the metals occurred in the

Table 5. Heavy metal concentrations in *Terminalia catappa* tissues (mg/kg)

Heavy Metals	Root	Shoot	Stem	Fruit
Arsenic (As)	1.52 ±0.22 [a]	1.4 ±0.27 [a]	2.11 ±0.73 [ab]	1.09±0.49[a]
Chromium (Cr)	2.89 ±0.17 [ab]	1.23 ±0.44 [a]	2.59±0.32 [ab]	1.43±0.74 [a]
Nickel (Ni)	1.92±0.94 [a]	1.21 ±0.12 [a]	1.32 ±0.78 [a]	1.08±0.45 [a]
Copper (Cu)	28.14±3.04 [d]	22.71 ±0.54 [d]	24.56±6.48 [d]	19.31 ±6.32 [bc]
Lead (Pb)	9.44±1.57 [b]	6.37 ±0.66 [b]	12.33±1.47 [c]	4.21 ±1.73 [b]
Zinc (Zn)	18.73±1.07 [c]	14.28 ±1.65 [c]	23.42±3.92 [d]	11.23 ±1.45 [c]
Cadmium (Cd)	4.71±0.87 [b]	3.89 ±0.11 [b]	2.45±0.48 [ab]	1.87 ±0.17 [a]
Iron (Fe)	38.46 ±6.47 [de]	34.93 ±7.38 [de]	53.22±10.22 [e]	28.35 ±4.22 [d]

sequence of Fe > Cu > Zn > Pb > Cr > Cd > As > Ni. The probed metals in the stem also recorded iron (Fe) to have had the highest concentration (53.22±10.22 mg/kg) while nickel (Ni) has the lowest concentration at 1.32 ±0.78 mg/kg. Therefore, the heavy metal composition observed in all parts of the plant exceeded the permissible limits [19]. Arsenic was recorded as the heavy metal concentration at 1.09±0.49 mg/kg in *Terminalia catappa* obtained from the automobile workshop. The magnitude of occurrence in the parts of the plant was as follows: stem > root > shoot > fruit. The fact that there are more heavy metals in the stem can be a result of mineral transportation from the roots to the shoots and leaves of the plant. Minerals are translocated to the shoot for plant growth and development through the vascular system (phloem and xylem) of the plant that is located in the stem [34]. This finding is also in line with Sulaiman and Hamzah [35], who studied the accumulation of heavy metals in roadside plants.

The maximum allowed limit according to FAO, EU and WHO for arsenic, chromium, nickel, copper, lead, zinc, cadmium, and iron in mg/kg are 0.02 (FAO), 0.85 (WHO), 0.20 (EU), 0.20 (WHO), 0.01 (WHO), 5.0 (WHO), 0.10 (WHO), and 5.0 (WHO), respectively. In our study, iron was recorded to be the highest heavy metal in the fruits with a value of 28.35±4.22 mg/kg, while nickel had the lowest, having a concentration of 1.08±0.45 mg/kg. The order of occurrence of these heavy metals in the fruit was as follows: Fe > Cu > Zn > Pd > Cd > Cr > As > Ni. The metals showed a similar trend with respect to the level of occurrence within the plant tissues investigated except for the stem, in which chromium was higher in concentration than the cadmium. The scrutinized heavy metals in the plant samples exceeded the recommended permissible limits expected to be seen in plants. Arsenic (V) is an analog of phosphorus which is an essential mineral for both plants and animals. Arsenic accumulates mainly in the liver and kidney as well as in the lungs and in chronic cases even in the skin and hair. This metal induces cancer in the lungs, bladder and skin via oxidative stress in humans as it inhibits the activity of thiol groups such as glutathione by binding with them and forming complexes with arsenic (As). It can also inhibit the generation of energy in the form of ATP (adenosine triphosphate) by interfering with the phosphorylation processes that convert ADP to ATP during glycolysis [36]. Chromium was found to occur in concentration in the plant parts as follows: root > stem > fruit > shoot. This pattern of concentration could be a result of the transfer coefficient. It surpassed the permissible limit (0.85 mg/kg) stipulated by WHO/FAO [18] and recorded a value of 1.43±0.74 mg/kg. Chromium can perform functions in its trivalent (Cr (III)) or hexavalent (CR (V) states. In its hexavalent state, it facilitates agents that improve insulin levels and sensitivity aiding patients with diabetes (Cr VI can serve as a cofactor to insulin) [37]. Chromium can bind directly to DNA to form DNA complexes which are stable and cause breakage in DNA strands. It also causes skin ulcerations [38]. Nickel recorded at 1.08±0.45 mg/kg which was above the limit (0.2 mg/kg) specified by WHO/FAO [18]. It bioaccumulates in the liver, kidney and lungs. It aids in iron reabsorption, biosynthesis of some enzymes like hydrogenases (in microbes), and acts as a cofactor to ureases. Toxicity levels of nickel cause lung cancer, angina and skin rashes [39]. Lead concentration in the fruit overshot the permissible concentration limit in the plant which is 0.01 mg/kg. It had 4.21±1.73 mg/kg as its value and has no known safe level within the human system. Its accumulation order is as follows: stem > root > shoot > fruit. This high concentration of lead in the plant could be attributed to excess fuel combustion by vehicles being serviced in the workshop and the fact that the roots of *Terminalia catappa* may have spread to the auto electrical servicing workshop soil since the plants are growing just within the area (2 to 4 ft. distant). The servicing of car batteries which contain a high amount of lead, eventually contaminates the soil with lead. Lead has a range of adverse effects. It can interfere with hormonal vitamin D, reproductive and developmental systems, the nervous system and it can cause cancer [38]. The zinc concentration in the various plant parts were all above the permissible limit set by WHO/FAO [21].

The value recorded within the fruits was 23±1.45 mg/kg. It had the third highest concentration in the heavy metal assayed. This may have been attributed to the wastes generated from the wear and tear of automobiles during repairs and servicing and unscrupulous or unprincipled disposal of auto parts. The cadmium concentration observed in the fruit was 1.87±0.17 mg/kg. Cadmium generally accumulates in the liver and the kidneys. It is a cumulative toxin and carcinogenic [14]. The iron concentration in the fruit observed in *Terminalia catappa* was the highest heavy metal concentration (28.35±4.22) found at the site. The concentration level may have been a result of increases in metal constructions done in the workshop. Iron is needed by *Terminalia catappa* leaves for the photosynthetic activity that aids growth and development [34]. Iron, found in blood, bone marrow and muscles, serves as a cofactor to some enzymes. At toxicity levels, it causes GIT disorders, liver failure, cirrhosis and red blood cell disorders [40].

Table 6 shows the results of the bioconcentration factor, the translocation factor and the bioaccumulation factor. These are phytoremediation properties of *Terminalia cattapa* fruit. The bioconcentration factor (BCF) is an important tool that is used to determine environmental risk assessment since it denotes the accumulation potential of these heavy metals from the soil to the plant parts [41]. It denotes the phyto-stabilization ability of the plant, thereby minimizing the mobility of the heavy metals in the environment, or their bioavailability, by preventing them from leaching or entering into the food chain. When a BCF value is > 1, it suggests that there is a potential in the phyto-stabilization ability of that plant part, while a BCF of < 1 indicates that there is no possible potential for phyto-stabilization. Cadmium had the highest bioconcentration factor (1.15) while arsenic and lead had concentration factors of 0.66 and 0.42, respectively, and iron was recorded as the least bioconcentration factor. The order BCF ability (or stabilization ability) of the tropical almond fruit was: Cd > As > Pb > Cr > Ni > Cu > Zn > Fe. BCF values obtained for all the heavy metals investigated had values that were < 1, except for Cd, suggesting a possible phytoremediation potential for cadmium using *Terminalia catappa*.

The translocation factor (TF) is a model used to determine the translocation ability of these assayed heavy metals from the plant's roots to the shoots. It is a measure of the rate at which a plant can tolerate heavy metals in its tissues (heavy metal containment), or its phytoextraction ability. A translocation factor value greater than one (> 1) suggests that the plant can translocate these metals to other plant parts while a factor less than 1 signifies poor translocation of these exploited metals to other parts of the plant from the root [42]. The translocation factor (TF) of arsenic was the highest at 0.92 followed by iron with a value of 0.91. The lowest observed was chromium with a factor of 0.42. The translocation factor of the heavy metals within the plant tissues ranged as follows: As > Fe > Cd > Cu > Zn > Pb > Ni > Cr. The TF values of the exploited metals were all < 1, suggesting limited phytoextraction ability of the fruit or translocation of these metals to the fruit. This poor translocation ability and bioconcentration ability may have been because *Terminalia catappa* sequesters these metals in the soil by excreting chemical substances that can convert them to a

Table 6. Phytoremediation potential of *Terminalia catappa* (tropical almond)

Heavy Metals	BCF	TF	BAF
Arsenic (As)	0.66	0.92	0.47
Chromium (Cr)	0.36	0.43	0.17
Nickel (Ni)	0.25	0.63	0.14
Copper (Cu)	0.23	0.80	0.16
Lead (Pb)	0.42	0.67	0.19
Zinc (Zn)	0.07	0.76	0.04
Cadmium (Cd)	1.15	0.83	0.45
Iron (Fe)	0.02	0.91	0.012

relatively less toxic state. It is also possible that it facilitates a phytovolatilization, taking up these metals and converting them to volatile compounds that are eventually released into the atmosphere. This appears to be the case since it has a higher TF than BCF.

The bioaccumulation factor (BAF) is also a model used to evaluate the phyto-corrective ability of *Terminalia catappa*. The bioaccumulation factor recorded for arsenic was the highest (0.47) followed by cadmium (0.45), while the lowest recorded bioaccumulation factor, 0.04, was seen in zinc. The order of arrangement in terms of BAF values was As > Cd > Pb > Cr > Cu > Ni > Zn > Fe. The BAF values obtained for the heavy metals investigated were all less than one (< 1) which suggests that this fruit poorly accumulated these heavy metals. The results obtained from the BCF, TF and BAF suggest a flawed phyto-corrective feasibility of the tropical almond plant in the automobile workshop site.

Table 7 reveals the potential risk assessment associated with those consuming this fruit obtained from the vicinity of the automobile workshop. The lodgement of heavy metals in *Terminalia catappa* may present health risks that may turn out to be carcinogenic or non-carcinogenic. The daily intake rate of *Terminalia catappa* was obtained from the consumption survey of the target population proved to be 0.028 kg/person/day while the average adult weight of the targeted population was 58.5kg. Iron had the highest consumption value (0.0136 mg/kg/day) while nickel as a heavy metal in the fruit was ingested the least (0.000517mg/kg/day). The estimated daily intake (EDI) for the ingested heavy metals was as follows: Fe > Cu > Zn > Pb > Cd > Cr > As > Ni. This puts forward that the consumption of heavy metals found in *Terminalia catappa* at the automobile workshop site provided more of Fe and Cu. The estimated daily intake of these metals was found to be for arsenic 5.21×10^{-4}, chromium 6.84×10^{-3}, nickel 5.17×10^{-4}, copper 9.24×10^{-3}, lead 2.02×10^{-3}, zinc 5.38×10^{-3}, cadmium 8.95×10^{-4} and iron to be 1.36×10^{-2} (all units were mg/kg/day). The established EDI for all heavy metals investigated were all below the oral RFD recommended by USEPA [10] although Pb at 2.02×10^{-3} mg/kg/day was close to EDI when compared to the stipulated oral RFD (3.5×10^{-3}mg/kg/day) set by USEPA as against other metals and their EDI. The toxic hazard quotients for the metals investigated were observed to be as 0.104, Cr 0.000456, Ni 0.026, Cu 0.231, Pb 0.577, Zn 0.017, Cd 0.895 and Fe 0.019, respectively. The toxic hazard quotients (THQ) investigated for the metals in black almond fruit were all below one (< 1), informing us that there was no potential health risk or non-carcinogenic risk posed by the consumption of the fruit obtained from this site. The sum total of the hazard quotient or hazard index was approximated as 1.869. This indicates only a mild or moderate hazard or non-carcinogenic risk for the consumers. The sequence of the hazard quotient of the metals investigated in this fruit can be seen as follows: Cd > Pd > Cu > As > Ni > Fe > Zn > Cr, meaning that if there were to be a health risk, it would originate with Cd and Pb obtained from the consumption of black

Table 7. Health risk assessment of heavy metals for adults

Heavy Metals	EDI (mg/kg/day)	THQ	ILCR
Arsenic (As)	5.21×10^{-4}	0.104	7.82×10^{-3}
Chromium (Cr)	6.84×10^{-4}	0.000456	3.42×10^{-4}
Nickel (Ni)	5.17×10^{-4}	0.026	8.79×10^{-4}
Copper (Cu)	9.24×10^{-3}	0.231	1.85×10^{-5}
Lead (Pb)	2.02×10^{-3}	0.577	1.7×10^{-5}
Zinc (Zn)	5.38×10^{-3}	0.017	0
Cadmium (Cd)	8.95×10^{-4}	0.895	2.34×10^{-5}
Iron (Fe)	1.36×10^{-2}	0.019	0

almond. Ekere *et al*. [9] also observed that cadmium posed health risks in food crops grown in a dumpsite. The toxic hazard index of the heavy metals estimated was 1.869, indicating that there was a mild or moderate non carcinogenic health risk associated with the ingestion of black almonds obtained from this site.

The incremental lifetime carcinogenic risk (ILCR) results of the metals As, Cr, Ni, Cu, Pb, Zn, Cd and Fe are as follows: 7.82×10^{-4}, 3.42×10^{-4}, 8.79×10^{-4}, 1.85×10^{-5}, 1.7×10^{-5}, 0, 2.34×10^{-3} and 0, respectively. Arsenic, lead, chromium, nickel, copper and cadmium were investigated since they are the metals at the finger tips when cancer is in question. As stipulated by USEPA, the acceptable inconsequential cancer risk is a value within 10E-06 to 10E-04. The total cancer risk obtained was given as 4.379×10^{-3}. This value is far greater than the acceptable limit for cancer risk. This number makes it clear that ingestion of black almond from this site can potentially lead to cancer.

Cadmium contributed more than 50 % to the total cancer risk. Cadmium has been reported to persist within the body system for between 16-33 years, causing several metabolic dysfunctions, DNA aberrations or damages, fatal development complications and ailments such as renal failure. Various kinds of cancer have also been attributed to long-term exposure to it [43]. While there is a risk of developing cancer from the consumption of tropical almond in this automobile workshop, the non-carcinogenic health risk assessment suggests that the hazard from consuming these fruits is a moderate one. It also suggests that such health risks (carcinogenic and non-carcinogenic) are strongly associated with cadmium.

4. Conclusions

The research offers a glimpse of how the damage done by the wastes generated from automobile workshops manifest in the soil and by extension to humans. This damage results mainly from the heavy metals that have been released into the environment. From the results obtained, the uptake of heavy metals by tropical almond fruit all exceeded the limit stipulated by FAO and WHO. These levels were caused by waste emanating from the workshop sites. Therefore, it is pertinent to make the target population know about the dangers of indiscriminate waste disposal and the dangers of consuming these tropical almonds used as shedding plants in their workshops.

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