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Potato, a Goldmine, Now a Biological Time Bomb: A Case Study of Uptake of Heavy Metals by Tubers of Potato in Jos-Nigeria

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ABSTRACT: The uptake and accumulation of heavy metals by plant roots occurs through an inter-related network of physiological and molecular mechanisms, including the binding of metals to extracellular exudates and cell wall components. The objective of this work is to investigate heavy metals uptake by five selected potato varieties commonly grown in Jos, Nigeria, using standard methods. The concentrations of heavy metals in water, soil and potato samples were analyzed using AAS after complete dissolution by mixed acid digestion (HF/HCl). The data obtained were subjected to descriptive statistics and then compared with the WHO/FAO acceptable limits. The results obtained were alarming: iron, lead, and cadmium were above the recommended threshold by 277, 6,400, and 1,233%, accordingly, from the water sources from Jos North, while concentration levels of Jos South were beyond acceptable limit by 138, 5.6, and 50%, accordingly. Marabel had the highest heavy metal uptake in Jos South; Fe, As, Cd, Zn, and Pb were beyond the tolerance limit threshold by 1,666,43,13440,74 and 128%; while Caruso accumulates more heavy metals compared to other varieties in Jos North at a threshold value of 843,37,40,323,138, and 107%. Potato tubers cultivated within the study areas were highly concentrated as reported herein, this will, overall affect human, animal health, aquatic life and crop productivity.

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Potato (*Solanum tuberosum* L.) is the world's fourth most important food crop both in production and in area under cultivation (Zhany *et al.,* 2017). The yield of potato in Africa stands at 20 t/ha with a continental average of 13 t/ha; more than half of the global output is produced in developing countries, almost one-third of the output is harvested in China and India alone, while China is the leading producer in the world with 99 million metric tons (FAOSTAT, 2019). The establishment of the Potato Research Centre, Kuru-Plateau State by the National Root Crops Research Institute (NRCRI) in 1976 marked the beginning of rapid expansion of potato production in Nigeria. Despite notable efforts devoted to the development and transfer of new technologies to improve potato production in Plateau State; including potato seeds multiplication, training of farmers, potato research, breeding and selection of new improved varieties; annual potato production in the state stands at 900,000 metric tonnes (Jwanya *et al.,* 2014). This output level has not been increasing at farm level, while yields have continued to decline substantially, and remain lower than potential yields (FAOSTAT, 2015). This is an indication that technological advances generated through research and investments have not widely translated into improved efficiency; in response to

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this, several varieties were released. There are several cultivars of potatoes in the world, the most common in Nigeria include: Nicola yellow, Nicola GL, Marabel, Bertita, Ditta amongst others (Wailare and Madu, 2018). Potato has a more dominant place in the diets of people in developed and developing countries, since it can be grown within 80 – 90 days, it matures as compared to 9–12 months for other tubers such as yam and cassava. Nigeria is the fourth largest potato producer in sub-Saharan Africa and seventh largest producer in Africa, with an output of 1,284,370 metric tons and yield per hectare of 37,201 kg/ha (3,720.1 kg/ha) (FAOSTAT, 2019). Domestic consumption of both fresh and processed potato stands at 4.63kg/capita (FAOSTAT, 2015). The crop is widely cultivated in commercial quantities in Plateau state; although, it is an underexploited food crop with a huge unrealized potential to improve food security, income and human nutrition (Schulte-Geldermann, 2013). Potato can grow quickly, cheaply, and free entire populations from hunger. Potatoes have a high nutritional value, with a high content of proteins, vitamins C, B6, B1, folic acid, minerals such as potassium, phosphorus, calcium and magnesium, and micronutrients such as iron and zinc (Peng *et al.,* 2018; Burlingame *et al.,* 2009).

Jos has a high altitude and thus a cool climate, which promotes production of potatoes in the area (Wuyep *et al*., 2013); relics of abandoned tin mines and tin ore processing sites abound in the area. This indicates a high possibility for the heavy metals to be present in the area given the prevalence of mining activity (Bian *et al*., 2016), furthermore, Jos has a huge potential to produce clean potato for consumption using several sources of water, but this has been threatened by the evidences of the presence of heavy metals in the ponds, earth dams, and community tube wells within the state; all beyond the tolerance levels for safety standards (Lar et al., 2014; Mafuyai *et al.,* 2020).The major entry point of heavy metals into the environment is through mining of solid minerals (Tsafe *et al*., 2012). Mining involves the extraction of naturally occurring minerals from the earth crust (Nukpezah *et al.*,2017). When mining a particular metal, the entire soil mass is excavated, laid bare, and exposed to the environmental agents of degradation, weathering and transportation, this results in soil erosion and extensive contamination of the surrounding areas. The entry point of heavy metals is through plants, also via food chain and consequently through the soil (Musilova *et al.,* 2017). Heavy metals are considered as one among the most important environmental concerns due to their toxicity and accumulation in the body (Arora *et al*., 2008).

Heavy metals (HMs) are majorly released due to anthropogenic activities like mining, smelting procedures, steel and iron industry, chemical industry, traffic, agriculture, domestic activities, and tannery. HMs may enter into surface and ground water, soil, and are ultimately taken up by plants in toxic forms; when consumed can cause serious concerns to human health. The use of water contaminated with heavy metals for irrigation over long periods of time increases the heavy metal concentration above the permissible limit (Javid *et al*.,2018).Irrigation is a vital practice in agriculture that involves supplying water to crops to support their growth and increase agricultural productivity (FAO,2012). However, the water used for irrigation is often polluted due to various human and animal activities, leading to potential risks for both the environment and human health. In many regions, water sources used for irrigation are contaminated by pollutants from human activities such as industrial discharges, sewage and wastewater disposal, and the use of chemical fertilizers and pesticides (FAO, 2012). These pollutants find their way into rivers, lakes, and groundwater, which are then utilized for irrigation purposes. Additionally, animal activities like livestock farming contribute to water pollution through the discharge of animal waste and by products into water bodies (FAO, 2013). The presence of heavy metals has become a worldwide concern due to toxicity, ubiquity, persistence, non-biodegradability, and bioaccumulation in water, soils and its gradual uptake by plants is now regarded as one of the most severe ecological problems worldwide (Javid et al., 2018).Heavy metal uptake in soils around abandoned minefields is a potential risk to plant and animal health due to the accumulation of the heavy metals by plants and subsequent introduction into the food chain (Olatoyinbo et. al. 2018). The soil is the main depository of heavy metals, given the surface it exposes and its structure; it accumulates anthropic influences, depending on its adsorptive and exchange properties (Muntean *et al*., 2019). Though some heavy metals are required in trace quantities like Copper (Cu), iron (Fe), manganese (Mn), nickel (Ni), and zinc (Zn), in excess these metals may become extremely toxic. However, non-essential metals, such as aluminum (Al), arsenic (As), cadmium (Cd), lead (Pb), and mercury (Hg), are not required for normal biological function and may quickly lead to toxicity (Javid *et al.,* 2018; Tchounwou *et al.,* 2012). The Accumulation and effects of heavy metals through consumption of potatoes and its vegetables from these mining soils are of great concern in the study area. However, the five varieties of potato; Diamant, Caruso, Marabel, Bertita, and Green leaf Nicola were planted in the study area. The harvested tubers were conveyed to the laboratory for further analysis of heavy metals, in order to ascertain the extent of accumulation of heavy metals for each of the variety. Generally, the presence of these toxic elements in the soil and agricultural crops are associated with the use of fertilizers and the presence of ions that can bind these metals (Couto *et al.,* 2018; Defarge *et al.,* 2018). Yohanes *et al.,*(2020) posited that spraying of insecticides and fungicides and the use of compost can cause an increase in Fe, Pb, Cd, and Cr metals in potato plants. The uptake of heavy metals by humans through consumption of some farm produce, has been reported in literatures from different parts of the world (Tsafe *et al.,*2012), but most were cultivated and collected from unknown sources, where the status of the soil and water used to irrigate the crop are uncertain. Boise *et al.,* (2020) reported that heavy metal concentrations in potato varied in relation to varieties, when they assessed the presence of heavy metals in tubers of Potato in Benin, Nigeria; even though the potatoes were purchased from the open market. Hence, the objective of this work is to investigate heavy metals uptake by five selected potato varieties commonly grown in Jos, Nigeria.

MATERIALS AND METHODS

Jos - North local government is located at the extreme North of Plateau State on Latitudes 09 53 and 09° 591 North and Longitudes 08° 511 and 09° 021 East; while Jos south local government area is located between latitude 8^0 43N and Longitude 8^0 46E. It is situated at the north western part of the state with its headquarters at Bukuru, which is about 15 km from the state capital, Jos (Oiganji and Dikam, 2020).

Sampling Procedure for Water and Analysis: River Dilimi was the source of water used to irrigate the experimental site at Jos North. Ten sampling stations were mapped out at the interval of 150 meters length from each other. Three stations were randomly selected using Simple Random Sampling Technique from the ten stations mapped out, after which they were numbered from 1-10 to serve as representative of the ten stations, which covered the study area. Calibrated water drawer was used to collect water samples from the surface and at 120 cm depth of each of the three randomly selected stations along the river. Polythene bottles with screw caps were well labeled and were used to fill them with the collected samples for laboratory. Six (6) water samples were collected three times for every six (6) weeks. Details about the laboratory procedure are as reported by Oiganji and Dikam (2020).

Kuru Dam was the source of water for the experiment at Jos South, the length of the dam was measured and mapped-out to be 1600 meters. Three (3) sampling stations were mapped-out at equal interval of 533meters, where samples were collected at each station. Nine (9) water samples were collected at the depth of 50cm .The samples were collected at these stations, in a well-treated container to avoid interference and impurities coming in contact with the samples. The samples were collected for every six (6) weeks at about 9 am, accordingly; details are as reported by Stella, (2023).

Soil samples were collected at 15 cm depth concurrently at both experimental plots using soil auger, to ascertain the presence of heavy metals in the soil. The soil samples were analyzed at Nigerian Institute of Mining and Geosciences, Jos. The different standard solutions collected from both experimental fields were prepared for AAS analysis under Beer-Lambert method of metal analysis as reported by Samkwar, (2015), Dalen, (2015) and Dapam, (2015).

Agronomic Practices: Twenty (20) sacks of cement were washed thoroughly and allowed to dry before putting the soil samples to avoid any acid or liming condition from the bags. Soil samples were taken from the field at a depth of 10 cm from the soil surface, and then measured using a weighing balance with the same weight of 15kg of soil for each sack. The length and breadth of the sack was measured and given the total of 9.18m^2 using a measuring tape. Five (5) varieties: Diamant, Caruso, Marabel, Nicola and Yellow Leaf were laid in a randomized complete block design (RCBD) replicated 3times and then randomly assigned into 15 experimental plots. The five (5) varieties of Potatoes were planted on the 8th of February, 2022 in both plots. The seeds were planted inside the sack at a depth of 4 to 6cm. Irrigation was done frequently (every day) in the morning using four litre container for each variety. After planting, the five varieties of potatoes later germinated with different days of emergence as follows: Diamant (after 6days), Yellow leaf (after 5days), Caruso (after 7days), Marabel (after 11days), and Bertita (after 14days). After fourteenth days of planting, all the five varieties germinated with 80-85% germination rate. Each experimental sack consists of three (3) seed per sack giving the total of 80plant stand in the experimental layout. Weeding was done manually at seven (7) weeks after sowing. N.P.K 15:15:15, fertilizer was applied and the rate of fertilizer per hectare is 600kg (12 bags), while the rate of 0.55kg per the area of each sack (9.18m^2) was applied on the 1st of March, 2022, four weeks after sowing. Readings were taken from three weeks after sprouting (1st of March, 2022) and on a weekly basis for seven weeks. The plants were harvested manually using a hand trowel for easy harvest due to the nature of the sacks after 65days of planting. Each tuber yield from the sacks were collected inside a stainless container and weighed using a weighing balance. Harvested yield were taken to the laboratory to ascertain the extent of accumulation of heavy metals at Nigerian Institute of Mining and Geo-sciences, Jos. Detailed report about the growth parameters and tuber yield are as reported by Emmanuel, (2023) and Anisa, (2023).

Data Analysis: Data obtained was subjected to ANOVA using SAS 4 version, while the analysis for soil, water and heavy metals, were compared with established permissible limit, and were subjected to T-test using SPSS version 11.1.

RESULTS AND DISCUSSION

Status of Heavy Metals in Source of Water used for Irrigation: The results obtained when the water from river Dilimi in Jos North were analyzed, shows that Cd, Pb, and Fe were above the permissible level (WHO, 2019) by 1233, 4430, and 299%, accordingly for Jos North. This confirms what Aliyu *et al.*, (2019) reported, that lead and Fe were above the permissible level in Jos North. The Pb and Cd value were 200 and 1790% higher than the expected permissible limit in the Dam used to irrigate the experimental field in Jos South, however, the value of Cu and Zn were within the permissible limit as shown in Fig. 1. Oiganji and Dikam (2020) reported that zinc and copper were within permissible limit, which is at par with the outcome of this research.

Table 2 shows the status of heavy metals in Jos South, it can be seen that Cu, Pb, and Zn values were below the tolerance threshold as recommended by WHO (2019), whereas Zn, As, and Fe were far above the permissible threshold value of 151, 132, and 10,675%. It can be seen that for both experimental sites, the Fe value were astronomically higher compared to other heavy metals, this may be due human activities around the study areas like dumping of spare parts of vehicle in the water bodies used for irrigation, which has built-up over time in the soil.

This can damage the gastrointestinal systems, which could cause nausea, vomiting, diarrhea and stomach pain to humans, over time it may cause fatal damage to the brain and liver of humans (Javid *et al.,* 2018); while in plants excess iron could cause stunted growth and discolored bronzing foliage.

Heavy Metal Status in the Soil: Table 1 shows the status of heavy metal in the soil in Jos North, it can be seen that Copper (Cu), Lead (Pb), Zinc (Zn) were below the tolerance limit for heavy metals in Soils as recommended by WHO, (2019) standard, though a null value was recorded for Cadmium in both sites. However, Arsenic and Iron were far above the permissible value of 287, and 29,697% as indicated in Table 1. When Arsenic is beyond the tolerance limit in the soil and if absorbed by humans, it interact strongly with proteins and enzymes that cannot be metabolized by the human body, and eventually cause the organic matter in the body to lose biological activity, it may further cause severe poisons; skin manifestations and vascular diseases in humans (Tchounwou *et al*., 2010)

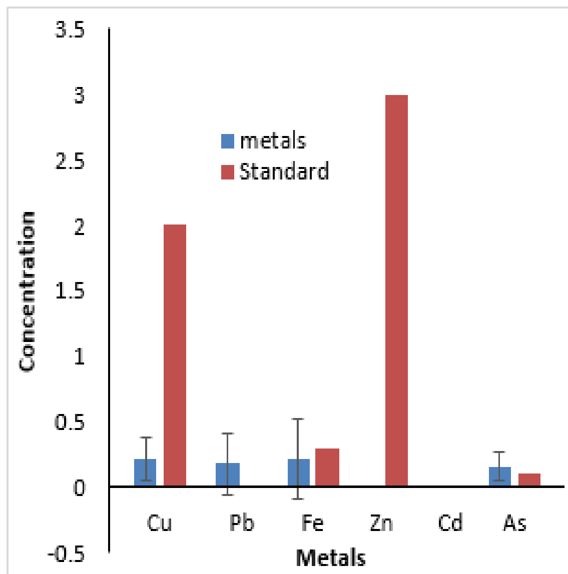

Fig.1 Concentration of metals with respect to permissive limit

Uptake of Heavy Metals in Tubers of Potato: Table 3 shows the uptake level of the five varieties of potato that was cultivated in Jos North, Cu and Zn values in the tubers were far below the permissible level, with exception of Caruso whose value of 3.42 ppm was far beyond the tolerance limit value of 3.0 as presented in Table 3.

However, Cd, Pb, As and Fe for Jos South were higher than the acceptable value by 40323, 38462, 4412, and 2043%, accordingly, as presented in Fig. 1. David et al., (2021) investigated the level of heavy metals in selected fruits sold commonly in Jos, Nigeria, they reported very high value of cadmium present in Avocado pear, Black currant, Egg Plant, Golden melon, and Soursop, which confirms what was reported herein. Caruso tubers displayed an exceptionally high uptake of heavy metals more than other varieties. Though, Yellow leaf variety uptake appears to be least for Cd, Pb, and Zn, while Daimond uptake value for Cu was least among all the varieties considered.

Table 1: Heavy metal Concentrations, ppm in Soil (Jos North)

Heavy metals	Cd (ppm)	Cu (ppm)	Pb (ppm)	Zn (ppm)	As (ppm)	Fe (ppm)
Soil Sample	ND	20.98	23.96	17.44	57.35	9562.5
WHO (2019)	0.8	36	85	50	20	32.2

N.D= Not Detectable

Table 2: Mean value of heavy metals from soil in Jos South

Heavy metals	Cd (ppm)	Cu (ppm)	Pb (ppm)	Zn (ppm)	As (ppm)	Fe (ppm)
Soil Sample	N.D	22.73	39.58	75.63	26.47	3437.5
WHO (2019)	0.8	36	85	50	20	32.2

N.D= Not Detectable

Table 3: Mean values of Heavy Metals Status of potatoes cultivated in Jos North

Varieties	Cd (ppm)	Cu(ppm)	Pb(ppm)	Zn(ppm)	As(ppm)	Fe(ppm)
Diamant	0.4032	0.2591	2.1368	2.9948	1.2255	39.530
Caruso	1.2097	1.5544	3.8462	3.4180	2.2059	183.83
Yellow Leaf	0.4032	0.5181	0.8547	1.7904	1.9608	97.222
Nicola	1.2097	0.7772	1.2821	2.2318	0.7353	91.880
Marabel	0.4032	0.5181	2.5641	2.2135	1.7157	83.333
WHO (2019)	0.003	2.0	0.01	3.0	0.05	9.0

Table 4 shows the uptake extent of the heavy metals considered in the research for Jos North, from Table 2 Cadmium value in the soil was negligible, however, Table 4 shows that Diamond and Yellow Leaf value of Cadmium was also negligible, but Caruso and Nicola varieties recorded Cadmium value of 1.02ppm which was above the recommended threshold value of 0.003. The values of Cu for all the varieties were below the permissible level of 2.0, even though the value of Cu in the soil was below the recommended value as presented in Table 2. Nevertheless, Marabel variety recorded the highest uptake value of Cd, Cu, Pb, Zn, As, and Fe, and they were above the tolerance level by 34030, 34188, 181, 9804, and 1293%.

Table 4: Mean values of Heavy Metals Status of potatoes cultivated in Jos South

Varieties	Cd (ppm)	Cu(ppm)	Pb(ppm)	Zn(ppm)	As(ppm)	Fe(ppm)
Diamond	ND	0.5181	1.2821	5.2735	3.4314	96.154
Caruso	1.2097	0.5181	2.1368	4.1341	1.4706	42.154
Yellow Leaf	ND	0.2591	1.7094	10.432	2.4510	115.45
Nicola	0.8065	0.5181	3.4188	5.0455	2.9412	56.624
Marabel	1.0209	0.7772	3.4188	5.434	4.9020	116.38
WHO (2019)	0.003	2.0	0.01	3.0	0.05	9.0

This is quite alarming and disturbing; hence in an area contaminated by heavy metals, Marabel should not be planted in Jos South, this confirms what Boise et al., (2020) posited, that heavy metal concentrations in potato varied in relation to varieties, when they assessed the presence of heavy metals in tubers of Potato in Benin, Nigeria.

Conclusion: River Dilimi in Jos North, is the major source of water used to irrigate most vegetables sold in Farin Gada market, most residents in Jos buy vegetables and potatoes from this market; while Kuru Dam serve as source of water for National Root Crop Research Institute, Vom and neighboring communities, However, due to the excessive presence of Lead, Cadmium, Arsenic, Copper and Zinc in the water, it is clear that human health, animals' productivity, aquatic life and crop productivity is at high risk as a result of bioaccumulation. Hence, it is obvious that what is thought to be healthy food, in the long run may turn out to be a keg of gun powder which unassuming, ignorant members of the populace sit on, which will sooner or later go off. The resultant complications are numerous, including a bone softening disease known as Osteomalacia, cancer, nervous system disorders, skin lesions, immune system dysfunction, birth defects, acute abdomen, and liver disease. Therefore, detailed caution should be put in place so that water quality analysis for heavy metals should be carried out for mining ponds, before it is used for irrigating vegetables and other crops in Jos.

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