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Potential of Sweet Potato (*I. Batatas*) for Phytoremediation of Heavy Metals and Organochlorine Residues from Abandoned Mine Agricultural Areas of Riyom LGA, Plateau State, Nigeria

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Abstract: Agricultural activities are taking place on/or around abandoned tin mine areas on the Jos Plateau, Nigeria. Agricultural practices on mine soils intensify contamination of soils by heavy metals and pesticide residues and the challenging problem to produce food safe for human or animal consumption. This research examines the potentials of sweet potato (*Ipomoea. batatas*) for the phytoremediation of heavy metals and organochlorine residues on/around abandoned tin mine agricultural areas in Riyom LGA, Plateau State, Nigeria. The water, sediment, soil and plant samples were collected and air dried. Soil, sediment and plants (divided into seed, root, stem and leaves) samples were then ground in an agate mortar and pestle to pass through a 0.5 mm stainless steel sieve. Heavy metals determinations in soil, sediment and the sweet potato samples were achieved by using Energy Dispersive X-Ray Fluorescence spectrometry (ED-XRFS), the available fractions were analyzed by MP-AES while GC/MS was used to detect and quantify the pesticide residues. Soils of Riyom agricultural mine areas were found acidic in nature and had low cation exchange capacity, non-saline, elevated concentration of toxic metals and low nutrient contents. The mean total concentrations of Cr, Cu, Ni, Mn, Zn and Fe in soil were 636.32, 646.98, 267.47, 1626.76, 160.39 and 145988.93mg/kg respectively. The available fractions were higher than the WHO limits for irrigation water. The tuber accumulated the highest concentrations of Cr, Cu and Ni, but Mn, Zn and Fe were with the highest concentrations in the leave. The BCF of sweet potato in this work range from 0.63 in Fe to 27.18 in Cu signifying that of sweet potato is an accumulator of most of the metals and the translocation factors were from ND in Zn to 3.87 in Fe. All the 18 OCP residues detected in sweet potato were above the MRL and the FFDCA limits but hept. epoxide was not detected in the sweet potato sample. Estimated Daily Intake (EDI) for y-BHC, aldrin, dieldrin, endrin, endrin aldehyde and endrin ketone exceeded the ADI for 32.7kg (children) and the ADI for 60kg (adults) categories indicating very high potential health risk through consumption. Sweet potato absorbed and translocates significant amounts of heavy metals and OCP residues in their roots, stems and leaves which show the plant could be used for the phytoremediation of heavy metals and pesticides residues.

Keywords: Potential, Sweet Potato (Ipomoea. Batatas), Phytoremediation, Heavy Metals, Organochlorine Residues, Abandoned Mine

1. Introduction

Mining and processing have caused numerous environmental damages, which include ecological disturbance, destruction of natural flora and fauna, pollution of air, land and water, instability of soil and rock masses, landscape degradation and radiation hazards. The environmental damage has in turn resulted in waste of arable lands [1]. These wastes from mining and processing include a variety of chemicals like heavy metals [2]. Soil pollution is causing significant losses of income as well as impacting the human health and threatening the food security of the most vulnerable population [3]. The contamination of agricultural soil is of special concern. Bansah, and Addo [4] reported that post-mining land use should be one that contributes most effectively to the productive capacity and stability of the ecosystem. The post-mining land use in recent times determines the reclamation planning. However, disturbed mining lands can be contaminated with high concentrations of heavy metals that may be absorbed by the crops. A relatively new technology for the removal of heavy metals from contaminated sites is phytoremediation. Phytoremediation is the use of plants to remove organic and/ or inorganic contaminants from soil (phytoextraction), uptake and conversion into non-toxic forms (phytovolatilization), or stabilization of an inorganic into a less soluble form (phytostabilization) [5].

Plants possess and use a variety of mechanisms to deal with the contaminations especially heavy metals, hydrocarbon compounds and man –made chemicals such as herbicides, fungicides, pesticides. Plants sequester them in their cell walls. Plants also chelate these contaminations in the soil in inactive forms or complex those in their tissues and can store them in vacuoles, away from the sensitive cell cytoplasm where most metabolic processes occur [6, 7]. The uptake of organic pollutants from soils by plant roots is mainly driven by simple diffusion based on their chemical properties and bioavailability. Several detoxification enzymes are involved in the transformation and sequestration of organic pollutants in plants. Cytochrome P450 enzymes (CYP) play vital roles in the oxidative process for emulsifying highly hydrophobic pollutants [8]. Sweet potato (I. batatas) has been selected for investigation based on its root morphology and propagation characteristics; it's extensive widely branded fibrous root system results in a large root surface area per unit volume of surface soil and also, being capable of providing larger surface for colonization by soil microorganisms [9]. This plant species is able to survive and reproduce on soils heavily contaminated with Zn, Cu, Pb, Cd, Ni, Cr, and As. The main goal of this investigation therefore is to evaluate the potentials of sweet potato (I. batatas), a dicotyledonous plant species which grows on abandoned mine agricultural soil for phytoremediation of the contaminated soil with heavy metals and pesticide residues. Plants grown on mine spoils appear to represent useful tools for soil remediation and environmental restoration at low cost [10].

2. Materials and Methods

2.1. Study Area

The study was carried out at Makera in Riyom Local Government Area of Plateau State. Riyom is situated at an altitude of about 4200ft (1280m) above sea level. It is 8° 45´East; 9° 43´North of the Equator with an average rainfall 1300mm to 1500mm and the rainy season extends from late March to early October. The average daily minimum temperature is 17°C; the mean monthly range temperature is between 13.9°C and 31.1°C while the mean relative humidity at noon varies between 14 and 74% [11].

2.2. Collection of Samples

2.2.1. Water, Sediment and Soil Sampling

Soil samples from Makera in Riyom Local Government Areas of Plateau State were collected from abandoned tin mine agricultural areas. The agricultural soils were taken in triplicate at 0-10cm, 11 – 20cm and 21 – 30cm depths at different locations using spiral auger of 2.5cm diameter and mixed and bulked separately to form a composite sample of each depth before they were placed in clean labeled plastic bags and transported to the laboratory [12]. The water and sediment samples were obtained from streams and ponds around the mine ponds used for the irrigation. The samples were used for heavy metals analysis by Energy Dispersive X-Ray Fluorescence spectrometry (ED-XRFS) and MP-AES for speciation studies.

2.2.2. Plant Sampling

Sweet potato (leave, stem and tuber) samples were randomly collected from nine agricultural mine areas. The leave, stem and the tubers (were chopped into pellets) into different containers and air dried. The dried samples were ground into powder with mortar and pestle. The powdered samples were used for heavy metals and OCP residues analysis.

2.3. Speciation Studies of the Soil /Sediment Samples

The soluble fractions of the metals in the soil/ sediment were extracted with the water from the stream or pond in the ratio soil/sediment: water (1:5). For the exchangeable and specifically adsorbed fraction extractable, 1g of soil/ sediment sample was weighed into 50ml extraction tube. 25ml of solution 0.11M acetic acid was added into the tube to make a mixture with the soil sample. The mixture was shaken in the extraction tube for 6 hours at room temperature using a mechanical shaker. The mixture was centrifuged at 3000rpm for 10minutes and the supernatant immediately was used for analysis or stored at 40°C prior to analysis with Micro Plasma Spectroscopy [13, 14].

2.4. Extraction of Pesticide Residues from Vegetable Samples for GC –MS Analysis

The pesticide residues were extracted from vegetables by USEPA 3510 method using ethyl acetate as the solvent. Sodium hydrogen carbonate ($NaHCO_3$) was used to neutralize any acid that may be present and the vegetable samples were washed thoroughly with distilled water. Twenty grams (20g) of each of the sample was placed in a mortar and anhydrous sodium sulphate (Na_2SO_4) was used to dehydrate the sample matrix. After weighing, the samples were washed thoroughly with distilled water and placed in a mortar and ground to a paste using a pestle. The paste was transferred into a conical flask with the help of a spatula and 40ml of ethyl acetate was added and shaken thoroughly. A 5g portion of sodium hydrogen carbonate ($NaHCO_3$) was added to the mixture followed by 20g of anhydrous sodium sulphate (Na_2SO_4) and the entire mixture was shaken vigorously for one hour and the mixture was filtered into a labeled container before being centrifuged at a speed of 1800 rpm for 5mins. This process was to ensure that enough of the pesticide residue dissolved in the ethyl acetate. The organic layer was decanted into a container and a 1:1 mixture of 5 ml ethyl acetate and cyclohexane was added. The procedure was repeated for each of the sample [15, 16].

2.5. Cleaning up of Sweet Potato Extracts

A 10mm chromatographic column was filled with 3g activated silica gel and topped up with 2 to 3g of anhydrous sodium sulphate, and 5 ml of n-hexane was added to the column. The residue in 2 ml n-hexane was transferred into the column and the extract was rinsed thrice with 2 ml hexane. The sample was collected in a 2 ml vial, sealed and placed in the refrigerator in the laboratory with temperature below normal room temperature to prevent evaporation of the ethyl acetate [14].

2.6. Analytical Procedure

2.6.1. Heavy Metals Analysis by ED-XRF

The ED-XRFS machine was switched on and allowed to warm up for two hours. Finally, appropriate programs for the various elements of interest were employed to analyze the samples material(s) for their present or absence. The result of the analysis was reported in percentage (%) of the oxides of the metals.

2.6.2. GC-MS Determination of Organochlorine Pesticides (OCPs)

2000ppm (Catalog Number: M-8080) containing 18 OCPs components was purchased from AccuStandard and five (5) point serial dilution calibration standards (0.10, 1.00, 5.00, 10.00, 100.00ppm) was prepared from the stock and were used to calibrate the GC-MS. Prior to calibration, the MS was auto-tuned to perfluorotributylamine (PFTBA) using already established criteria to check the abundance of m/z 69, 219, 502 and other instrument optimal & sensitivity conditions. Determination of the levels of OCPs in the sample was carried out using GC-MS by operating MSD in selective ion monitoring (SIM) and scan mode to ensure low level detection of the target constituents. Agilent 6890A gas chromatograph coupled to 5973C inert mass spectrometer (with triple axis detector) with electron-impact source was used. The stationary phase of separation of the compounds was HP-5 capillary column coated with 5% Phenyl Methyl Siloxane (30m length x 0.32mm diameter x 0.25µm film thickness). The carrier gas was helium used at constant flow of 1.2 mL/min at an initial nominal pressure of 026 psi and average velocity of 40.00 cm/sec. 1µL of the samples were injected in splitless mode at an injection temperature of 250°C. Purge flow to spilt vent was 30.0 mL/min at 0.35 min with a total flow of 31.24 mL/min; gas saver mode was switched off. Oven was initially programmed at 50°C (1 min) then ramped at 25°C/min to 100°C (3 min) and 5°C/min to 300°C (5 min). Run time was 51 min with a 3 min solvent delay. The mass spectrometer was operated in electron-impact ionization mode at 70eV with ion source temperature of 230°C, quadrupole temperature of 150°C and transfer line temperature of 300°C. Acquisition of ion was via scan mode (scanning from m/z 50 to 500 amu at 2.0s/scan rate) and selective ion mode (SIM). After calibration, the samples were analyzed and corresponding OCPs concentration obtained [17-21].

2.7. Data Processing and Statistical Analysis

In this study, the translocation factor (TF) and the bioconcentration factor (BCF) were calculated using the ratio of the heavy metal concentrations in the shoots and roots [TF = shoot/root] and the ratio of the heavy metal concentrations in the shoots and soil [BCF = shoot/soil], respectively [22]. The heavy metal data were subjected to a one-way analysis of variance (ANOVA) using the Statistical Package for Social Science (IBM SPSS Statistics 23) and the means were separated by using Turkey post hoc test (at $p < 0.05$).

3. Results and Discussion

3.1. Physico – Chemical Properties of the Soil and Sediment from Abandoned Mine of Riyom LGA

The pHs ranged for soil and sediment samples from Makera in Riyom LGA were from 5.46 in RYMM2 soil to 7.08 in the sediment of the same area (Table 1). Among soil properties, pH together with soil organic matter content is the major factor affecting metal solubility, mobility and availability [23]. The electrical conductivities (EC) were low with the RYMM3 subsoil with the lowest (0.05 dS/m) and the RYMM2 soil having the highest (0.39dS/m. In general irrigation water with an EC of < 0.75 dS/m (as in this work) were considered non-problematic for the growth of crops in the area but long term irrigation with the water will pose serious problem due to salinity [24, 25]. The percentage organic carbon was lowest (0.06%) in RYMMS and highest (2.46%) in RYMM2 subsoil. The RYMM2 and RYMM3 subsoil's have the highest (0.12%) nitrogen content and RYMMS was the lowest (0.03%). The organic matter was highest in the RYMM2 subsoil and lowest in RYMMS (sediment). The mineral content in the soil and sediment were in the order of P>Ca>Mg>K>Na. The exchange activities were almost the same ranging from 1.42 in RYMMS to 1.63 in RYMM3 subsoil analyzed. The cation exchange capacity and the percentage base saturation were highest in

RYMM3 subsoil lowest in RYMMS.

Table 1. *Physicochemical properties of sediment and soil with depth from Makera abandoned mine areas, Riyom LGA of Plateau State.*

Sample Code	pH	EC dS/m	OC %	N %	OM %	P ppm	K cMol/kg	Ca cMol/kg	Mg cMol/kg	Na Mol/kg	EA cMol/kg	CEC cMol/kg	PBS %	Clay %	Silt %	Sand %	Textural Class
RYMMS	7.08	0.17	0.060	0.003	0.10	2	0.021	0.51	0.26	0.0087	1.42	2.22	36.03	3.44	10	86.56	S
RYMM1	5.90	0.28	1.92	0.096	1.92	11	0.14	1.70	0.53	0.015	1.61	4.0	59.75	24.44	20	55.56	S,C,L
RYMM2	5.46	0.39	1.95	0.098	3.36	15	0.17	1.78	0.55	0.016	1.61	4.13	61.02	25.44	19	55.56	S,C,L
RYMM3	6.51	0.05	1.85	0.092	3.18	16	0.17	2.03	0.58	0.030	1.63	4.44	63.29	27.44	22	50.56	S,CL
SD																	

Key: RYMM = Riyom Makera, S = Sediment, Subscripts 1 = 0 – 10cm, 2= 11 – 20cm, 3 = 21 – 30 cm soil

Table 2. *Available forms of heavy metals (mg/kg) of soil and sediment samples of abandoned mine areas of Riyom LGA.*

LGA	Sample Area	Sample Code	As	Cd	Cr	Mn	Fe	Ni	Cu	Zn	Pb
Riyom	Makera	RYMMSS	0.13	ND	0.21	0.69	114.01	0.22	0.27	0.12	0.03
		RYMMSE	0.94	0.52	0.01	0.42	13.03	0.03	0.72	1.07	0.27
		RYMME	0.82	0.46	0.02	2.48	38.25	0.04	0.74	0.25	0.05
*WHO limit (irrigation water)			0.10	0.01	0.55	0.20	0.50	1.40	0.017	0.20	0.065

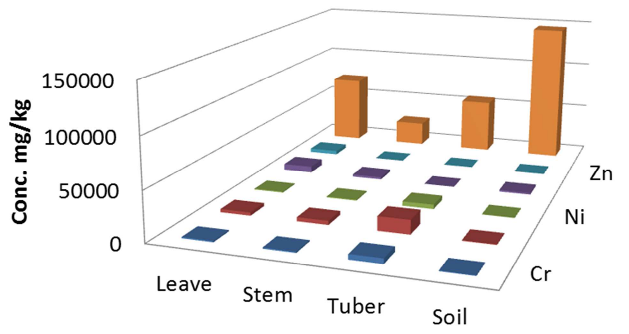
SS=soluble fraction, SE & E= Exchangeable and specifically adsorbed heavy metals in sediment and soil respectively. *Source = Chiroma *et al* 2014.

Table 3. *Bioconcentration, translocation and Biological factors of sweet potato.*

Plant	Bioconcentration Factor						Translocation Factor						Biological Accu. Factor					
	Cr	Cu	Ni	Mn	Zn	Fe	Cr	Cu	Ni	Mn	Zn	Fe	Cr	Cu	Ni	Mn	Zn	Fe
I. batatas	9.59	27.18	20.59	0.99	13.16	0.63	2.06	1.80	1.92	3.68	-	3.87	7.86	21.18	17.86	0.00	0.00	0.44

3.2. Heavy Metal Accumulation in Sweet Potato (I. batatas) Tissues

Results in Figure 1 showed the mean concentrations of heavy metals in sweet potato tissues.



	Leave	Stem	Tuber	Soil
Cr	1231.58	1163.16	5268.42	636.32
Cu	3274.84	4073.58	14377.36	646.98
Ni	865.33	944	4562.67	228.13
Mn	6429.58	2401.41	0	1626.76
Zn	4012.35	0	0	160.49
Fe	71633.35	24966.67	56622.24	145988.93

Figure 1. *The concentrations of heavy metals in I. batatas and soil.*

3.2.1. Chromium

The concentration of the metals in soil and the plant's tissues is reported in Figure 1. Cr concentrations were; 670.53 in the soil, 1163.16 in the stem, 1231.58 in the leaves and 5268.42mg/kg in the tuber. The intervention factor of between 70.2 and 85.8 (% clay between 20 and 25) [26] was far lower than what was obtained (670.53mg/kg) in this study. According to Marjanović et al. [27], if the concentration of a metal in the analyzed soil sample exceeded the intervention value it means that the location require remediation. Thus, Riyom soil was contaminated with Cr. Chromium exists in several oxidation states, but the most stable and common forms are Cr (0), the trivalent Cr (III) and the hexavalent Cr (VI) species [28]. Cr (VI) is one of the most toxic pollutants that are released into soils by various anthropogenic activities. It has numerous adverse effects not only on plant system but also on beneficial soil microorganisms which are the indicators of soil fertility and health. The use of sweet potato for the phytoremediation of the area showed the plant stored more of the Cr in the tuber and could not translocate the metal to the above ground tissues. The plant therefore could be more suitable for the phytostabilization of the metal.

3.2.2. Copper

The Cu concentrations were 646.98 in soil, 3274.84 in the leave, 4073.58 in stem and 14377.36 in the tuber. The intervention value of Cu is between 148.83 and 180.5 for the percentage of clay obtained in the area. This was over one third of the Cu in the soil. Copper is one of the essential micronutrients and its adequate supply for growing plants should be ensured through artificial or organic fertilizers. Cu occurs in the compounds with no known functions as well as enzymes having vital function in plant metabolism [29]. Daniel et al. [30] reported that when Cu concentration is greater than 20 mg/kg in soil, it is considered contaminated soil. The soils and Sediment of this study are therefore contaminated with the metal. Cu is a significant cause of ecological degradation where it occurs in receiving concentration above 0.5mgkg. [31]. The plant could be more suitable for the phytostabilization of the metal.

3.2.3. Nickel

Ni concentration ranged from 865.33 in the leaves to 4562.67 in the tuber. Ni concentration in the soil was 228.13 which indicated the soil was contaminated with Ni (intervention value of Ni is between 85.71 and 114.29 for the percentage of clay obtained). Ni is mostly used in metallurgical processes such as electroplating and alloy production as well as in nickel-cadmium batteries. It improves the structure of some plant enzymes and its low concentrations are essential for plant growth and sustainability of agro ecosystems. However, high concentration of nickel (Ni) has harmful effects on human health (such as cancer, lung problems and skin sensitivity) [31]. The plant therefore could be more suitable for the phytostabilization of the metal.

3.2.4. Manganese

Mn concentrations in this work ranged from ND in the tuber to 6429.58mg/kg in leave. Mn plays several roles in physiological processes in living organisms, including humans. Mn can constitute a nuisance in water if present in a high concentration with a characteristic metallic taste and staining properties. High Mn content decreases concentration and attentiveness of children in classes and neurotoxicity has been implicated for adults of over 50 [31]. The plant could be more suitable for the phytoextraction of the metal.

3.2.5. Zinc

Zn was not detected in stem and tuber but had 4012.35mg/kg in leave. The most common element that is found in the earth's crust is zinc and is found in all three spheres of earth that is atmosphere, hydrosphere and lithosphere showed its presence in the biosphere and is present in all foods [7]. The main use of zinc is as anti-rusting agent that helps to prevent rust and corrosion which otherwise cause damage to steel and iron. Zn is essential for normal plant growth and their low availability leads to the reduction of nitrogen metabolism and protein synthesis, internode length and plant growth. However, zinc (Zn) has a toxic effect when it is absorbed by plants in high concentration which negatively affects physiological and biochemical processes of plant, thereby leading to reduction in plant growth and yield [31]. The plant therefore could be more suitable for the phytoextraction of the metal.

3.2.6. Iron

Of all the micronutrients, iron is required by plants in the largest amount. Fe concentrations were; 145988.93 in soil, 24966.67 in stem, 71633.35 in leaves and 56622.24mg/kg in the tuber. The Fe contents of the soils were higher than the safe limit of 425.00 mg/kg [33, 34]. The high concentrations of Fe in the soil samples may suggest a very rich anthropogenic source of Fe, which allows the accumulation of Fe in plant's tissues. High levels of exposure to iron dust may cause respiratory diseases such as chronic bronchitis and ventilation difficulties. The plant therefore could be more suitable for the phytoextraction of the metal.

Soluble fractions of various heavy metals in the soil samples as estimated by water-extractable forms showed most of the metals concentrations detected were above the FAO limit for irrigation water except Mn and Ni (Table 2). Different metals exhibit different fraction distribution patterns. The speciation or chemical form of metals governs its fate, toxicity, mobility, and bioavailability in contaminated soils, sediments and water [12, 14, and 30]. Usually, only the soluble and exchangeable forms are able to be absorbed and utilized by plants. After completely extracting the bioavailable fraction of metal from the soil, some of the tightly bound metals in the soil can be become bioavailable [14, 35]. Heavy metals are scarcely available at pH greater than 6.5, since they precipitate, whereas at pH lower than 6.5, absorption sites tend to be saturated and metals enter progressively into the mobile phase which can be absorbed by crops or contaminate water bodies [24, 36]. The high concentrations of the soluble forms of these metals on the abandoned mine agricultural lands are of high risks (especially for the presence of As and Pb) to the plants and to the consumers of vegetables cultivated on it. Cd, As, Mn, Fe, Cu, Zn and Pb were reasonably extracted from the soil with 0.11mol/L of acetic acid solution. 0.11mol/L of acetic acid is like rain water mixed with the natural chemical compounds of the soil, had concentrations above the WHO limit [37], therefore, the likelihood of the water to be of high risk.

Sweet potato stored higher concentrations of Cr, Cu and Ni in the tuber which implies it could be used for phytostabilization but Mn, Fe and Zn were stored mostly in the leaves which could be used in phytoextraction of these metals. Fast growing plants with high biomass have good metal uptake ability. The extensive root branching system of sweet potato makes it well- suited for phytoremediation applications. Hairy root cultures of sweet potato had the highest peroxidase specific activity, compared with cultures from carrot and kangaroo apple. Ipomoea genus also has been used in phytoremediation project where the presence of heavy metals in the environment is a concern [38]. The heavy metals contents in the edible roots tuber of the sweet potato exceeded the allowable quantities stipulated by various nations (maximum absorption values of 34.16 mg kg-1 for sweet potatoes). The results obtained in this research, indicated that the edible roots of the sweet potato has somewhat high capacity of absorbing and accumulating Cr, Cu, Ni and Fe. These quantities of Cr, Cu, Ni and Fe in the edible root are very dangerous for human health since as the values exceeded the allowable limits. As, Pb and Cd were below the XRF detection limit (%). Cr, Ni Fe, Mn and Cu concentrations were above the NESREA maximum permissive levels of agricultural soils but were within the USEPA and EU Commission's limit. The concentrations of most of the metals were above the intervention values of the metals but Zn concentrations were within the limits (37). Njoyim et al. [39] found Cd was very high in the tuber and grains of beans that according to them, could cause perturbation or the destruction of kidney filtration mechanisms in cells, stomach pain and serious vomiting, bone fractures, reproduction failures and even probable infertility, central nervous system disorders. Thus, it can be suggested from the results obtained that, plants growing in metal-contaminated soils (for example, abandoned mine sites) should not be considered for animal feed or human consumption but could be used for phytoremediation purposes. The assessment of plants efficiency for phytoextraction was carried out with the bioconcentration factor (BCF) and translocation factor (TF) [25]. The BCF values ranged from 0.63 in Fe to 27.18 in Cu (Table 3). The BCFs for Cr, Cu, Ni, Mn, Zn and Fe are greater than 0.5. These results suggest that the sweet potato is hyperaccumulating plant. Sweet potato could be one of the very few hyperaccumulating plants with the capacity for multiple metal bioaccumulation. The TF values ranged from 0 in Zn to 3.87 in Fe. With the exception of Zn, all the other metals have their TF above 1 which indicates that sweet, potato could be used for the phytoextraction of the metals.

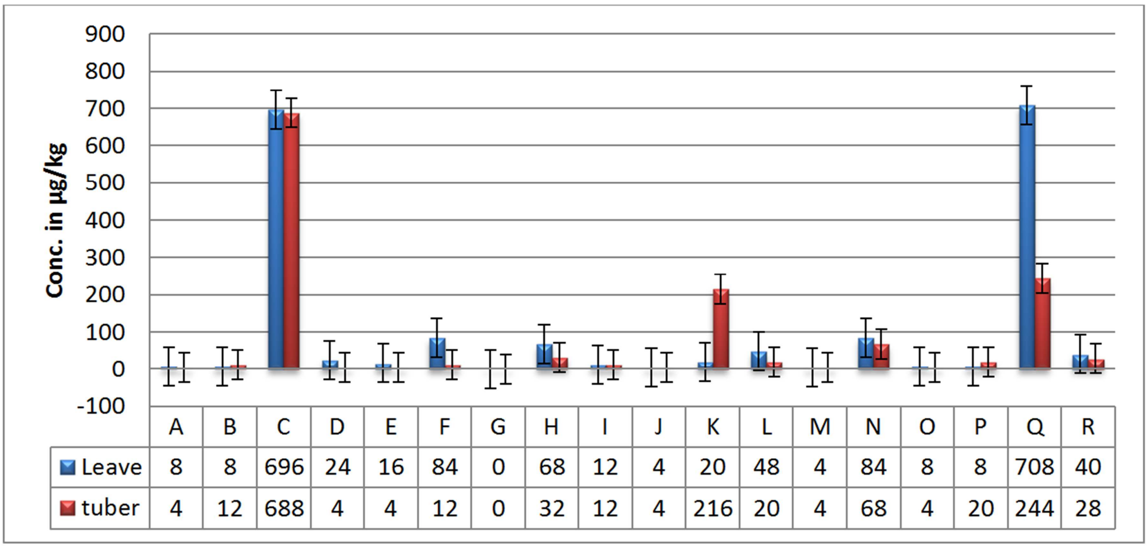


Figure 2. *Levels of OCP residues in Sweet potato leaves and tuber.*

Key; W=water; S= sediment, Subscript 1 = 0 – 10; 2 = 11 – 20; 3 = 21 – 30, A-a-BHC, B=b-BHC, C=y-BHC, D=d-BHC, E=Heptachlor. F=Aldrin, G=Hept. epoxide, H=a-endosulfan, I=Dieldrin, J=p', p DDE, K=Endrin, L=b-endosulfan, M=p, p' DDD, N=endrin aldehyde, O=p, p'-DDT, P= endosulfan sulphate, Q=endrin ketone, R=Methoxychlor

3.3. Concentrations of the OCPs in Leave and Tuber of Sweet Potato

The result of the Levels of OCP residues in Sweet potato leaves and tuber 1 is displayed in Figure 2 above. The result revealed that, the mean levels of the OCPs were; a – BHC was 4µg/kg (in tuber) and 8 µg/kg (in leaves), b – BHC was 12µg/kg (in tuber) and 8 µg/kg (in leaves), y- BHC was 688µg/kg (in tuber) and 696µg/kg (in leaves) and d- BHC was 4µg/kg (in tuber) and 16 µg/kg (in leaves) were detected in sweet potato from RYMM with average higher values in the leaves than in the tuber. The BHCs in sweet potato tuber and leaves were above the MRL and FFDCA (2015) [40] limits. 4µg/kg and 16µg/kg of heptachlor were detected in tuber and leaves respectively but hept. epoxide was not detected in the sweet potato sample. Aldrin and dieldrin both presented levels of 12µg/kg in tuber and 84µg/kg and 4µg/kg in the leaves. This is above the WHO MRL of 0.03µg/kg. The presence of aldrin and dieldrin in the sweet potato samples suggests the degradation of aldrin to dieldrin in the environment with probable fresh application of aldrin [15]. The levels of a – endosulfan was 32µg/kg in the tuber and 68µg/kg in the leaves, b – endosulfan level was 20µg/kg in the tuber and 48µg/kg in the leaves while endosulfan sulphate was 8 and 20µg/kg in leaves and tuber respectively. Endrin, endrin aldehyde and endrin ketone in sweet potato sample had values of 216µg/kg in the tuber and 20µg/kg in the leaves, 68µg/kg in the tuber and 84µg/kg in the leaves, and 244µg/kg in the tuber 708µg/kg respectively. DDD and DDE presented 4µg/kg in both tuber and leaves indicating aerobic, anaerobic while DDT presented 4µg/kg in tuber and 8µg/kg in the leaves; the likelihood of fresh application or non-degradation of the banned DDT pesticide in RYMM. Methoxychlor was detected in sweet potato tuber with concentrations of 28µg/kg in tuber and 40µg/kg in leaves. This shows that the sweet potato translocate more of the OCP residues to the leaves (though most pesticides are applied on the leaves) and therefore should be used for the phytoremediation of pesticides residues. The use of phytotechnologies to remediate these more persistent pesticides is only emerging. Difficulties remain including the potential phytotoxicity of some compounds (i.e. herbicides) that were originally developed destroy plant material. Typically the mechanisms involved in pesticide phytoremediation are phytodegradation, rhizodegradation, and phytovolatilization [41].

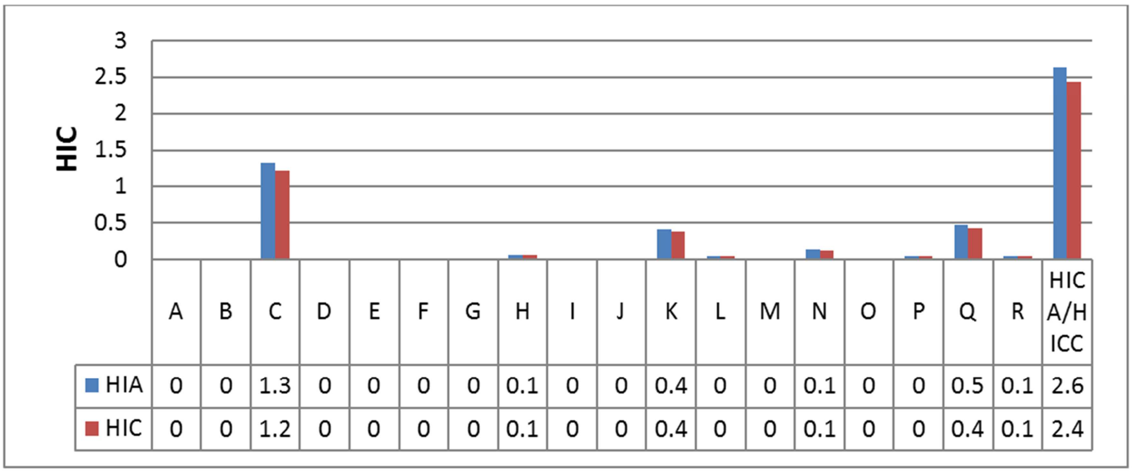


Figure 3. *Hazard indices and combined health indices of pesticide residues in sweet potatoes tuber.*

Key; W=water; S= sediment, Subscript 1 = 0 – 10; 2 = 11 – 20; 3 = 21 – 30, A=a-BHC, B=b-BHC, C=y-BHC, D=d-BHC, E=Heptachlor. F=Aldrin, G=Hept. epoxide, H=a-endosulfan, I=Dieldrin, J=p', p DDE, K=Endrin, L=b-endosulfan, M=p, p' DDD, N=endrin aldehyde, O=p, p'-DDT, P= endosulfan sulphate, Q=endrin ketone, R=Methoxychlor

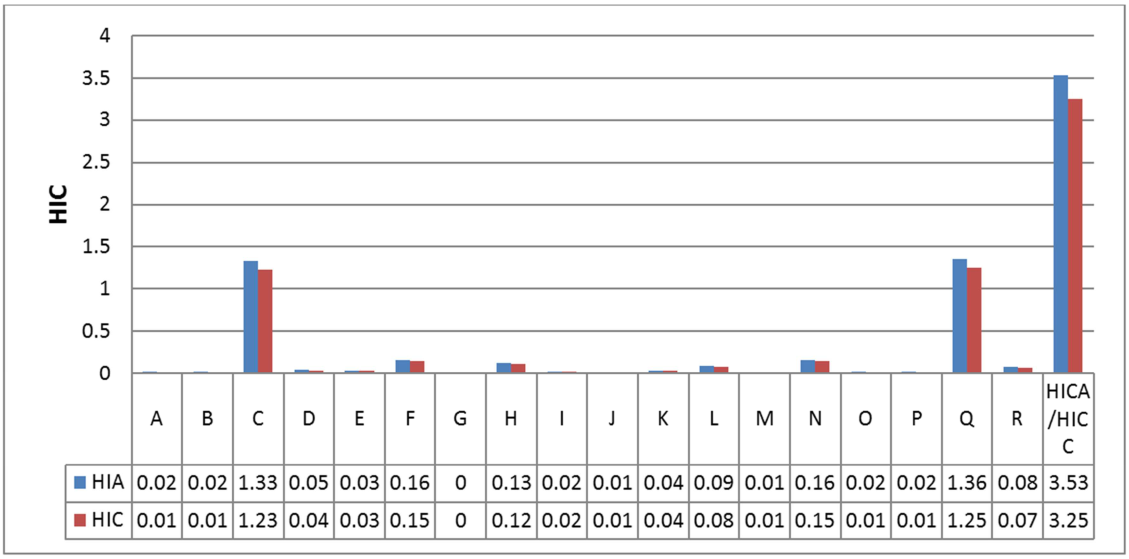


Figure 4. *Hazard indices and combined health indices of pesticide residues in sweet potatoes leave.*

Key; W=water; S= sediment, Subscript 1 = 0 – 10; 2 = 11 – 20; 3 = 21 – 30, A-a-BHC, B=b-BHC, C=y-BHC, D=d-BHC, E=Heptachlor. F=Aldrin, G=Hept. epoxide, H=a-endosulfan, I=Dieldrin, J=p', p DDE, K=Endrin, L=b-endosulfan, M=p, p' DDD, N=endrin aldehyde, O=p, p'-DDT, P= endosulfan, Q=endrin ketone, R=Methoxychlor

3.4. Hazard Indices and Combined Health Indices of OCP Residues

3.4.1. Hazard Indices and Combined Health Indices of OCP Residues in Sweet Potatoes Tuber

The study showed that health quotient (HQ) (Figure 3) was greater than 1 for y -BHC and also the combined health risks which suggests that, the consumption of sweet potato tuber from RYMM in the study is not advice able because is not free from risk of the studied pesticide residues.

3.4.2. Hazard Indices and Combined Health Indices of Pesticide Residues in Sweet Potatoes Leave

Also, the study showed (Figure 4) health quotient (HQ) was >1 for y –BHC, endrin ketone and also the combined health risk which suggests that the consumption of sweet potato leave from RYMM in the study is not advice able because of possible health risks. Vegetables take up pesticide residues and accumulate them in their edible and non-edible parts at quantities high enough to cause clinical problems to both animals and human beings. Excessive content of OCP residues beyond Maximum Residual level (MRL) leads to number of nervous, cardiovascular, renal, neurological impairment as well as bone diseases and several other health disorders [11].

4. Conclusion

As, Pb and Cd were below the XRF detection limit (%). Cr, Ni Fe, Mn and Cu concentrations were above the NESREA maximum permissive levels of agricultural soils and the intervention values of the metals but were within the USEPA and EU Commission's limit. Zn concentrations were within the limits. The BCFs and TF values for most metals studied were greater than 1 suggesting that the sweet potato is hyperaccumulating plant. Sweet potato accumulated most of OCP residues studied in its tissues that were above the MRL values and the leaves accumulated higher concentrations of the residues. This shows that the sweet potato translocate more of the OCP residues to the leaves and therefore should be used for the phytoremediation of pesticides residues. Sweet potato could be one of the very few hyperaccumulating plants with the capacity for multiple pollutants bioaccumulation Although the agricultural mine soils were contaminated with heavy metals and pesticide residues, foodstuffs and vegetables are still being produce on them due to high demand and also of the scarcity of arable lands.

5. Recommendation

Farming for the purpose of consumption or animals feeds should not be on or around abandoned mines areas. Crops that have low heavy metal/pesticide residues accumulation should be selected to reduce the adverse health effects of heavy metals/pesticide residues. Farmers should not select pesticide because of low cost but its toxicity should also be considered. The farmers should also adhere to the instructions on the pesticides' labels. Government should ensure only pesticide approved by appropriate authorities should be allowed into the country. There should be continuous monitoring of foodstuffs and the components of the environments to ascertain their safety as concerns heavy metals and pesticide residues. Records of pesticides victims should be documented for any reference.

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