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Effects of Pb and Cr Accumulation on the Growth Performance of Some Local Rice Varieties from North-Eastern Nigeria

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ABSTRACT

Rice is an important cereal crop and foods for many population which utilizes certain concentration of heavy metals as source of nutrient. Heavy metals contamination and food safety are global issues that requires attention. Nigeria local rice varieties; Mai-kaya, Jamila and Mai-kwalli were evaluated for effective agronomic response and phyto-extraction of Pb and Cr. The rice seeds grown in paddy farm for three weeks and transplanted to pots for heavy metals accumulation studies. 500 ppm of Cr and Pb were prepared and use to water the rice at its different concentrations (100mL, 200mL, 300mL, 400mL and 500mL). Growth parameters including root and leaf development were determine both in the field and after transplanting at 2-weeks intervals. The concentration of the heavy metals in dried sample of both rice organs and soil was determined by acid digestion and analyze using atomic absorption spectrophotometry (AAS). The growing plant in various Pb and Cr concentrations was found to produced root number at a range of 60.00 ± 2.00 to 38.33 ± 2.51, root length range of 11.43 ± 0.35 to 5.06 ± 0.20, fresh weight of 0.99 ± 0.01 to 0.40 ± 0.00 and dry weight of 0.85±0.17 to 0.13±0.00. Jamila was recorded with optimum plant height of 43.33, followed by Mai-kwalli with 38.33 after two weeks of treatment with Cr 100mg/Kg. For the phyto-extraction, Jamila and Mai-kaya demonstrate optimal Cr accumulation in their seeds and soil across all the concentrations. Jamila rice was found to be highly adaptive to various heavy metals concentration than Maikaya and Maikwalli. However, the the Pb and Cr values detected in the present study are beyond permissible limit. The maximum allowable limit for Pb is 300 µg/kg, while for the Cr is 0.2mg/kg.

Keywords: Rice, Agronomy, Cr, Pb, Phytoextraction

INTRODUCTION

Rice is consumed as staple diet by may populace in the world, specially in Africa and Asia. It has has two most abundant species including *Oryza sativa* (Asia) or less commonly occurring species *Oryza glaberrima* (Africa) (Mohammed et al., 2022; Mohammed, Samad, & Rahmat, 2018). Rice cultivation improves the food security glogally, making it the third-highest worldwide cereal production. Considering that, it has been considered as one of the most important food crop for human nutrition and caloric intake because it provides more than one-fifth of the calories consumed by humans (Kasote, Sreenivasulu, Acuin, & Regina, 2022). Depending on the type of rice cultivars, many requires much water as mean of irrigation, whereas some necessitate only mild amount of water flowing for natural process. Apart from water denseness, human activities Pbing to release of chemical in the soil equally affect rice productivity. Soil are mostly contaminated by different kinds of heavy metals such as mercury cadmium (Cd), (Hg), Pb (Pb), arsenic (As), chromium (Cr), zinc (Zn) and many more (Su, 2014).

Nevertheless, the metals are not only harmless to the plant, but also serve as nutrient at certain lower concentrations, hence it significant to determine their accumulations on the growing rice seeding's. If successfully achieved, it would provide insight on their effects and widen the scope understanding of rice as alternate plant species for phytoremediation. Upsurge in human industrial activities for example fertilizer company, agricultural activities (pesticide and insecticide), welding and paint production has resulted into large-scale release of waste and products containing heavy metals into the agricultural soils. Openly, heavy metals contamination occurs due to excessive deposition of toxic metals in the soil or water bodies. High concentration of such heavy metals can affect plant growth and development, as well as the rice consumers. Heavy metals are easily destroyed biologically but are only transformed from one oxidation state or organic complex to another (Zhou et al., 2020). Thus, heavy metal(s) pollution poses a great potential threat to the human health and their living environment.

Northern Nigeria is an agriculture based area where chemical fertlizers, and domestric and industrial waste are applied in the farms. The wastes serves as cheaper fertilizer that may increase the release of heavy metals in the soil due to its abundant usage. Because of the nature of application of the chemical fertilizer, domestic waste and the industrial waste, as well as accumulation of heavy metals in the soil by the plant, there is an urgent need for sustainable remediation strategy in order to protect both human and their environment. Interestingly, diverse rice varieties were discovered as capable of growing in heavy metals' contaminated soils. Therefore, it become crucial to test the potential of Northern-Nigeria local rice varieties for heavy metal uptake from contaminated soil and how the they affect the species at different developmental stages. Remarkably, soil has a natural capacity to attenuate the bioavailability and trasportation of heavy metals by means of antithetic mechanisms such as adsorption, precipitation and/or redox reactions. At higher concentration of the metals that can affect soil potential, the metals are mobilized resulting in serious contamination of the agricultural produce and environment.

MATERIALS AND METHODS

Sample Collection

The diverse local rice varieties' seeds were collected from different regions of North-eastern Nigeria which include Mai-kaya, Jamila and Mai-Kwalli.

Farmland Soil Digestion and Heavy Metals Determination

The soil samples used in this study was collected at a depth of 20 meters and grounded using mortar and pestle to enhance the oxidation. It was sieved through a 0.25 mm sieve mesh to obtain a fine particle for digestion and rice seeds germination. About 0.5g of the fine grounded soil sample was transferred into a 50ml beaker, and added 20ml of Nitric acid and Perchloric acid (1:1 molar ratio). The mixture was placed on a hot plate and heated gently at low temperature until dense white fumes of $HClO_3$ appeared. It was later allowed to cool, filtered into a volumetric flask which was filled to 50ml with distilled water and analysed for the presence of heavy metals using atomic absorption spectrophotometer (AAS).

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Nursery and Treatments (Heavy metals) Preparation

The farmland for the seeds pre-growing process was tilled and the soil samples were collected for subsequent nursery' pots preparation. The rice seeds were planted in the farmland, allowed to germinate and the seedlings were considered for nursery preparation after 3 weeks. Six pots for each rice variety were sets in the nursery for heavy metals analyses in a hard polyethylene bags containing 2kg of the soil sample. They were later transfer to Cr and Pb induced pots.

About 500ppm of Cr and Pb was prepared as described by (M. A. Islam, 2005), been the permissible amount for the growing of rice. This concentration was induced into the five individual pots per volume at varying volume as follows; 100mL, 200mL, 300mL, 400mL and 500mL of Cr and Pb respectively, while the six pot was set as control. The formulae for the preparation is as follows.

$$wt(mg) = \frac{Conc.\,in\,ppm\ \times Vol \times \%\,purite}{1000}$$

Determination of Growth Parameters

After proper watering of the soil to prevent hardening and aiding the seedling pulling, the seedlings from the farm lands were transplanted to the Cr and Pb contaminated soil at 2-3 cm depth. The plants were nurtured by proper watering to give rise to root, shoot/leaves and seeds development. Diverse growth parameters of the growing seedlings were recorded both in the farmland and after transplanting to determine the effect of the heavy metals on weekly basis. They includes leaf length, number of leaves, plant height, leaf area, number of roots, root length, fresh weight and dry weight. The experiments were terminated after eight weeks of transplanting, and the plants were harvested for Cr and Pb uptake/phytoremediation.

Analysis of Cr and Pb Uptake in Plant Organs and Experimental Uptake

Analysis for heavy metals uptake by the experimental rice varieties was carried out to determine the accumulation of the Cr and Pb in the soil and its concentration in the plant organs and in the soil. One gram (1g) of the powdered plant tissues and soil samples (air-dried for 14 days) were weighed into a beakers, and mixed with Nitric acid to Perchloric acid at 3:1 ratio. The mixture was warmed on a hot plate for 15 mins by stirring with a glass rod to enable it dissolve. The rest of the analysis was carried out as described above which subsequently analysed using AAS (Tőzsér, Magura, & Simon, 2017; Ugulu, 2015).

Statistical Analysis

The heavy metals accumulation of the diverse rice varieties was determined and statistically analysed as difference of means by SPSS version 18.0 (ANOVA) standard error (SE) at p <0.05.

RESULTS

Agronomic Response of the Local Rice Varieties Grown on Different Pb and Cr Concentrations

The rice varieties disclose different response to the heavy metals and uptake in their examined organs. Number of roots, root length, root fresh weight and root dry weight of all the rice varieties after treatment with Cr and Pb is presented in Table 1. Response to the metals showed that there is a highly significant difference (p <0.05) between variety and concentration interaction on number of roots. The result indicated that Jamila variety after treatment with 200mL (200mg/Kg) of 500ppm Cr had the highest number of roots (60.00), while Maikwalli variety at 500mg/Kg has the lowest number of roots (38.33). Equally, Maikaya variety has the highest root lengths (11.43) after treatment with 100mg/Kg of chromium,

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while Jamila variety has the least root length (5.06) on receiving 500mg/Kg of chromium.

Jamila was recorded with 1.60 and 0.40 as most highest and lowest fresh root weight (g) after treatment with 100mg/Kg and 500mg/Kg of Pb respectively. Further, the same Jamila variety after receiving Pb treatment at 100mg/Kg has the highest dry root weight (g) (0.82), while Maikwalli variety at 500mg/Kg chromium and 500mg/Kg had the lowest dry root weight (g) (0.12). The result for both the fresh root and dry root weight showed that there is highly significant difference (p <0.05) between variety, concentration and variety by concentration interaction.

Table 1: Agronomic response (root characteristics) of the local rice varieties grown under different Cr and Pb concentrations.

Concentration (mg/Kg)	No of Roots	Roots Length	Fresh Weight	Dry Weight
Control	58.66^{a}	11.48^{a}	0.94^{b}	0.60^{a}
Chrom. 100	57.00^{a}	10.54^{b}	0.90^{b}	0.41^{c}
Chrom. 200	54.33^{b}	10.25^{b}	0.84^{c}	0.28^{e}
Chrom. 300	47.55^{d}	8.85^{d}	0.75^{e}	0.25^{ef}
Chrom. 400	44.88^{e}	7.46^{e}	0.69^{f}	0.22^{f}
Chrom. 500	39.77^{f}	6.31^{f}	0.54^{h}	0.18^{g}
Lead 100	54.11^{b}	9.70^{c}	1.12^{a}	0.55^{b}
Lead 200	52.00^{c}	9.12^{d}	0.79^{d}	0.35^{d}
Lead 300	48.11^{d}	8.88^{d}	0.97^{f}	0.26^{e}
Lead 400	44.88^{e}	7.57^{e}	0.62^{g}	0.23^{f}
Lead 500	41.66^{f}	6.03^{f}	0.44^{i}	0.13^{h}
Variety				
Jamila	51.33^{a}	8.69^{b}	0.72^{b}	0.33^{b}
Maikaya	48.48^{b}	9.28^{a}	0.89^{a}	0.37^{a}
Maikwalli	48.27^{b}	8.26^{c}	0.65^{c}	0.25^{c}
Interaction				
Var*Conc.	***	***	***	***

The results for other agronomic characteristics of the local rice varieties after treatment with heavy metals was presented in Table 2. The significant difference (p< 0.05) between the varieties and treatments on plant height (cm) was found at week two, four and six respectively. It showed that Jamila and Maikwalli after treatment with 100mg/Kg Cr and Pb has the highest plant height (cm) (43.33 and 38.33) after week two. At week four, Maikaya (46.66) was found to have the highest plant height (cm) (200mg/Kg Pb treatment) and least (23.00) by receiving Cr 400mg/Kg. Further, Jamila was found to have leaf length (cm) of 43.00 and 24.66 at week six after Pb treatment at 100mg/Kg and 400mg/Kg respectively. For Cr treatment, Jamila has the high-grade leaf length (cm) (33.33) at 100mg/Kg, followed by Maikaya (17.66) at 400mg/Kg at week two. At week four and six, the results also indicated that Jamila produced lengthy leaves (30.66 and 17.00) after treatment with 400mg/Kg and 500mg/Kg Pb and Cr as most highest and least. Maikaya recorded (31.66) and Jamila (17.00) at week six after treatment with Cr at 100mg/Kg and 300mg/Kg respectively.

Number of leafs and leaf area (cm^2) of the experimental local rice varieties was also determined (Table 2). Maikwalli produced 4.33 (Pb 500mg/Kg), while Maikaya gave 2.33 (Cr 300mg/Kg) which recorded highest

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and least number of leaves at week two. At week four, Maikwalli (5.00) treated with 200mg/Kg Pb recorded highest leaf number and Maikaya (23.00) recorded least leaf number after receiving 500mg/Kg Cr. Still on number of leafs, Jamila produced 6.00 and 4.33 at week six (Cr 300mg/Kg, and Pb 400 and 500mg/Kg). At week two, Maikaya (11.20) and (5.36) recorded highest and least leaf area after treatment with Cr 200mg/Kg and Pb 500mg/Kg, whereas at week four, Maikwalli (17.60) recorded highest leaf area (cm^2) (Cr 200mg/Kg) and Maikaya (6.00) recorded lowest (Pb 300mg/Kg). Jamila (17.00) recorded highest and least (9.33) after receiving Cr 200mg/Kg and Pb 400mg/Kg treatments at week six. Interestingly, there is no significant difference ($p > 0.05$) between variety and treatment interaction, but there is significance difference ($p < 0.05$) between treatment on number of leaves at week two, four and six. The result show that there is significant difference ($p < 0.05$) between variety, treatment and variety by treatment interaction at week two on leaf area (cm^2). At four and six, the statistical analysis showed a significant difference ($p < 0.05$) between the variety and treatment, but there is no significance difference ($p > 0.05$) between variety by treatment interaction on leaf area (cm^2).

Phytoextraction of Pb and Cr by the Local Rice Varieties: Seeds, Root and Soil

Pb and Cr accumulation by the Maikaya rice variety is presented in Figure 1. It demostrate that soil accumulate higher concentration of Pb (203.34) and Cr (175.42), while seeds and roots has the least accumulation of Pb (16.32) and Cr (34.61) after treatment with 500mg/Kg and 100mg/Kg respectively.

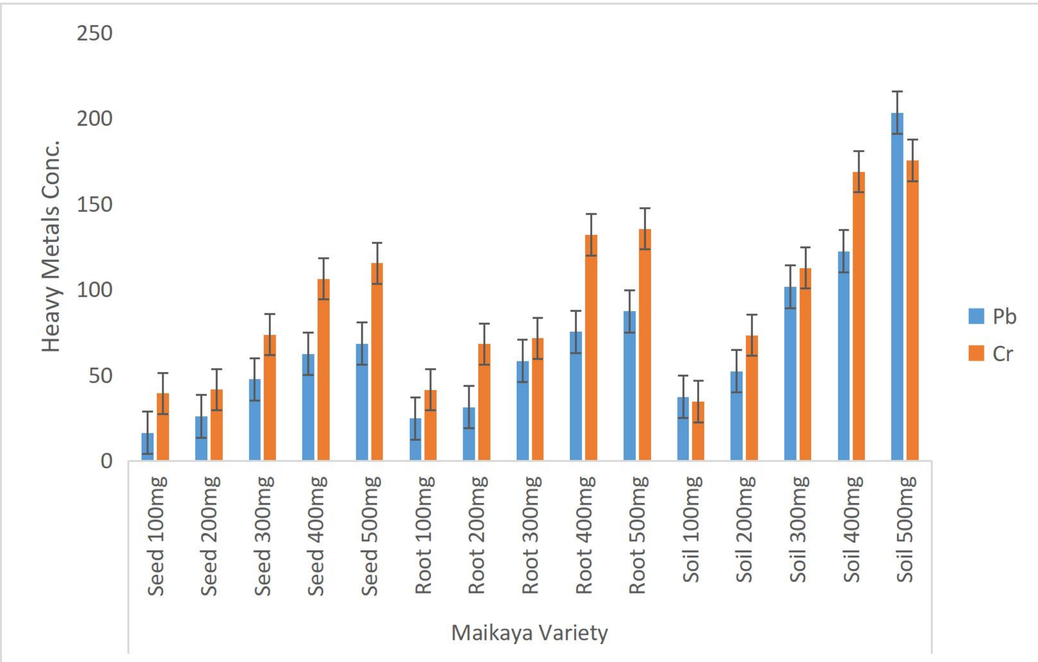

Figure 1: Pb and Cr accumulation by Maikaya root, seed and growing soil.

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Table 2: Agronomic response of the local rice varieties grown under different Cr and Pb concentrations.

Concentration (mg/Kg)	PHWK2	PHWK4	PHWK6	LLWK2	LLWK4	LLWK6	NLWK2	NLWK4	NLWK6	LAWK2	LAWK4	LAWK6
Control	40.94cd	38.83ab	39.16a	24.00bc	25.50a	27.33b	4.00ab	4.72a	5.27abcd	6.95bc	9.81cd	14.62b
Chrom. 100	40.77cd	34.44cd	34.00c	22.66bcde	25.66a	26.00b	3.22cd	4.33ab	5.33abc	6.93bc	9.21de	16.26a
Chrom. 200	41.11cd	32.22de	31.22d	21.00cde	23.66ab	22.88cd	3.33bcd	4.44ab	5.66a	7.73a	15.31a	16.45a
Chrom. 300	40.11d	30.22e	30.77d	21.88cde	21.88bc	21.55de	2.77d	4.33ab	5.55ab	6.60c	12.34b	14.73b
Chrom. 400	40.22cd	26.88f	26.66f	20.33de	20.22cd	21.88de	2.88d	4.11b	5.44abc	7.17abc	12.61b	14.64b
Chrom. 500	40.55cd	27.00f	25.77f	19.44e	18.77d	18.77f	2.77d	3.88b	5.11bcde	6.87bc	10.92c	12.61cd
Lead 100	41.77bcd	39.77a	36.55b	28.00a	23.66ab	28.88a	4.11a	4.77a	5.11bcde	7.27ab	8.27ef	11.36de
Lead 200	41.66bcd	39.22ab	33.00c	23.55bcd	25.00a	26.33b	4.00ab	4.33ab	5.22abcd	7.30ab	7.11fg	13.08c
Lead 300	41.88bc	36.66bc	31.00d	23.77bcd	23.33ab	24.00c	3.88ab	4.33ab	5.00cde	6.77bc	6.300g	10.13e
Lead 400	43.44a	38.88ab	31.11d	25.55ab	25.33a	23.11cd	3.77abc	3.88b	4.66e	7.18abc	7.24fg	11.55de
Lead 500	43.11ab	34.33cd	29.00e	20.33de	20.33cd	20.44e	4.00ab	4.11b	5.11bcde	5.60d	7.08fg	10.36e
Variety												
Jamila	41.77a	35.11b	34.25a	23.75a	24.55a	22.77b	3.58a	4.13b	5.13a	6.98b	9.25b	12.67b
Maikaya	41.55a	36.72a	32.22b	22.38a	23.83a	25.97a	3.44a	4.30ab	5.19a	6.35c	8.94b	14.26a
Maikwalli	40.80b	32.50c	30.38c	22.50a	21.33b	23.38b	3.69a	4.50a	5.27a	7.51a	10.81a	13.18b
Interaction												
Var*Conc.	**	***	***	*	***	***	NS	NS	NS	***	NS	*

PH= plant height; LL= leaf length; NL= number of leaves; LA= leaf area.

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Jamila Cr and Pb accumulation is presented in Figure 2. Equally, the growing soil accumulate higher concentration of the Pb (191.52) and Cr (185.67), while seeds demostrate least accumulation of both Pb (7.51) and Cr (11.28) at 500mg/Kg and 100mg/Kg treatment.

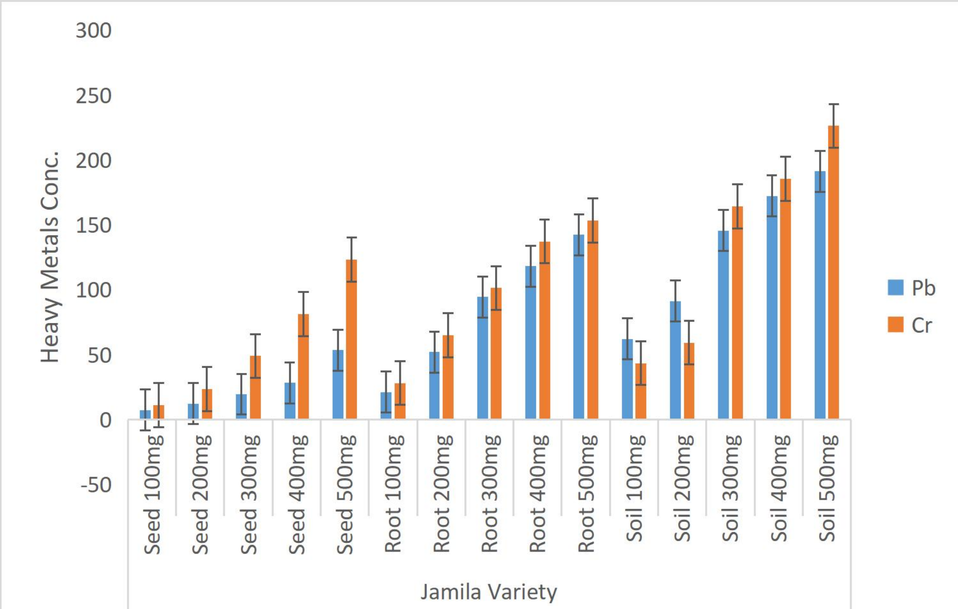

Figure 2: Heavy metals accumulation by Jamila root, seed and from the soil.

The Pb and Cr accumulation by Maikawalli local variety showed that the rice' root accumulate more Pb (139.51), while the growing soil had the lowest of its accumulation (19.65). Whereas, Cr accumulation by the soil was higher (185.29) and root was lowest at 100mg/Kg (Figure 3).

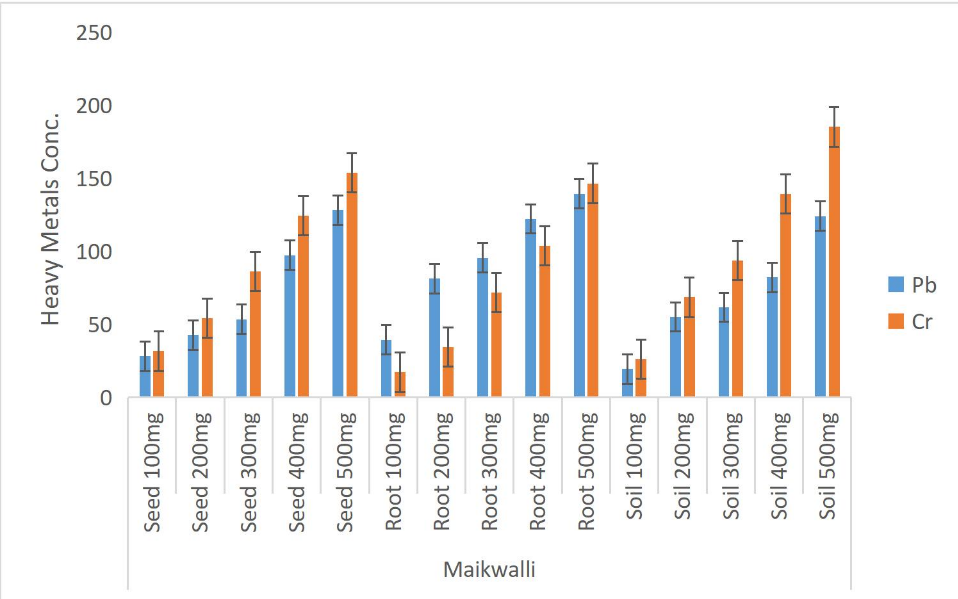

Figure 3: Heavy metals accumulation by Maikwalli root, seed and from the soil.

DISCUSSION

The Local Rice Varieties' Agronomic Response

Plants especially rice has for long been associated with heavy metals accumulation thereby serving as an agent of

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biotransformation. Heavy metals and plant species interact in their specific way, which depends on several factors such as soil type, plant, growth conditions, and the presence of other ions. In this research, several concentrations of Cr and Pb were assessed with a view to determine their impact on root characteristics. The various concentration were found to produced root number at range of 60.00±2.00 to 38.33±2.51, root length (cm) range of 11.43±0.35 to 5.06±0.20, fresh weight (g) of 0.99±0.01 to 0.40±0.00 and dry weight(g) of 0.85±0.17 to 0.13±0.00. In the overall results, it can be observed that an increase in the concentrations of Cr and Pb causes a decrease in the number of roots, root length (cm), fresh weight (g), as well as the dry weight (g). This is an indication that at maximum amount of metals (>400 mg/Kg) could be toxic to those local rice varieties (Faizan et al., 2024; Yadav, 2010).

Nevertheless, the rice cultivars developed a very potential mechanism to combat with such adverse environmental heavy metal toxicity problems (Kaur et al., 2021). In terms of plant height, Jamila variety after treatment with Cr and Pb 100mg/Kg and Pb after week 2 recorded the highest plant height. This is evident that the variety has the highest number of roots and root length (cm) which could ensure active nutrient transportation from soil to the shoots. Whereas, the highest leaf length in Jamila rice variety at 100mg/Kg lead could be attributed to the active adaptation of the cultivars as well higher number of other plant parts that could ensure normal plant physiological growth (Yue et al., 2019). For the number of leaves, Maikwalli produced the highest number of leaves of 4.33 at 500mg/Kg. (F. Islam et al., 2016; Shankar, 2020) reported that, Cr and Pb can affect plant growth at an increased concentration higher than 400 mg/Kg.

The results of the study also demonstrated that Jamila was found to be the most efficient in producing the highest number of roots, dry root weight (g) and root length (cm) than Maikaya and Maikwallai. The highly produced organs has a critical role to play in enhancing the rice growth. Specifically, the root if well-developed can enable the plant to absorbed water and mineral substances from the soil and transport up to the shoot (Shrestha, Kandel, Subedi, & Shah, 2020). This indicated that the variety could adapt better for growth and development, as well implies its acclimatization potential in the heavy metals contaminated environment. Contraversely, the growth of Maikaya and Maikwalli rice was found to be better in inducing length (cm) of the root while only Jamila that produce highest number of root 200 mg/Kg (K. Liu et al., 2020).

Local Rice Phytoextraction Potential

The heavy metal accumulation in rice might be affected by physical–chemical properties of the soil. Soil was reported to accumulate the highest concentration of Pb and Cr because it is serving as the reservoir. The accumulation process of the heavy metals in Maikaya rice at 400 and 500mg/Kg concentrations was found to give the highest accumulation capacity, although Cr was found to be accumulated compared to the Pb in the present study. This may due to the plants high affinity for Cr absorption and accumulation than Pb (K. Liu et al., 2020). Cr accumulation was found to be higher than Pb in all the concentrations in both seeds and soil. However, Cr accumulation in the root was only higher than Pb at 500 mg/Kg (Serbula, Miljkovic, Kovacevic, & Ilic, 2012). Jamila's heavy metals accumulation process is in order of increasing metal concentrations. The rate of the Pb accumulation was found to be lagging behind the Cr as it processes better the system.

Generally, the accumulation of high quantities of Cr rice roots shows that it is

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more bioavailable to plants than other heavy metals including Pb, resulting in a higher biological absorption coefficient. At 200, 300, and 400 mg/Kg, the rate of Pb accumulation by Maikaya was higher which implies its potency (Ashraf et al., 2020). Moreover, the maximum concentrations of metals accumulate in seed and root is ≤100. For Jamila rice variety is ≤150, while for Maikwalli is ≤140. These rice varieties demonstrates a great ability to accumulate metals ions and the concentration is higher than permissible discharge limit. FAO reported the permissible limit of heavy metal in food cannot exceed 50 mg/Kg (X. Liu, Li, Yin, Yan, & Wang, 2024). Furthermore, (Uddin, Zakeel, Zavahir, Marikar, & Jahan, 2021) reported the permissible limit in cereals and vegetables for Cr 1.3 mg/Kg. Therefore, the Pb and Cr values detected in the present study are beyond permissible limit. The maximum allowable limit for Pb is 300 µg/kg (Mlangeni et al., 2023), while for the Cr is 0.2mg/kg (Ijeoma, Chima, Daniel, & Ayotunde, 2010). Thus, the seeds cannot be consumed for health related issues as detected.

CONCLUSION

Pb and Cr agronomic response to the Pb and Cr contaminated and their phytoextraction characteristics were determined from local rice varieties. Heavy metals accumulated more in soil than in the roots and seeds. Jamila rice was found to be highly adaptive to various concentration of the metals than Maikaya and Maikwalli. Cr toextraction was more efficient than Pb which disclose the accumulating system of the rice varieties. Both 100 and 200 mg/kg of the metals were found to induce the production of roots, root length, fresh weight and dry weight. This study also demonstrates the interaction between metals and soil over a weeks influencing the production of leaf length, leaf area and number of leaves in the rice varieties. A small part of the Cr and Pb content of the rices at some concentration exceeds the standard permissible limits, whereas at high concentration it was far beyond the standard. Therefore, People may be at higher health risk from the use of higher accumulating rice.

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