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Cadmium in the roots and leaves of tea (*Camellia sinensis* L.) at PTPN 7 Pagar Alam unit, South Sumatra, Indonesia

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ABSTRACT

The excessive and intensive application of chemical fertilizers can increase the concentration of heavy metals in the soil. This study aimed to determine Cd deposition in tea roots and leaves using the Detailed Survey method, with sampling points determined using the stratified sampling method, which involves dividing the samples into several age ranges for the plants. The average concentration of Cd in the roots was 0.015 ± 0.004 mg/kg, while in the tea leaves it was 0.010 ± 0.003 mg/kg. The absorption of Cd in tea plant leaves shows the lowest average absorption rate in samples aged 15–25 years, particularly in plants that were 1 year old after production pruning, at 0.005 mg per plant. However, its content remains well below the maximum threshold of cadmium in tea, which was set at 1.0 mg/kg. The age of the plants does not substantially affect the accumulation of Cd in tea leaves; however, tea pruning does affect the accumulation of Cd in the leaves. The research findings indicate that the concentration of Cd in the roots and leaves of tea plants was very low, far below the established Cd threshold, influenced by regular pruning, which results in minimal Cd absorption in the tea leaves. Leaves were considered safe for consumption by humans and animals. Data on the levels of Cd in tea roots and leaves are still rarely found, so it was recommended to further investigate Cd in tea roots and leaves.

Keywords: accumulation, andisols, cadmium, fertilizer, tea

INTRODUCTION

Heavy metals were toxic chemical substances that pose significant environmental risks due to their non natural dissolution, leading to their accumulation in the environment (Siringoringo et al., 2022). Heavy metals come from natural sources and humans' activities, including weathering, air pollution, and extensive fertiliser use in agriculture (Fei et al., 2020). Cd can impair stomatal function in plants, thereby impairing the photosynthetic process (Guo et al., 2023). Cd was a hazardous pollutant that negatively impacts both the environment and human health (Johri et al., 2010). Andisol soil often has higher Cd content than other mineral soils due to the presence of allophane minerals, including amorphous forms (Tani et al., 2023). Andisol soil was highly conducive to plant growth due to its substantial organic matter content (Anda & Dahlgren, 2020). Andisol soil was located in several regions of Indonesia, including PTPN 7 Unit Pagar Alam in Gunung Dempo Village, Pagar Alam District, South Pagar Alam Regency, and South Sumatra Province.

Balanced fertilisers can improve the provision of essential nutrients for plants, promoting optimal growth (Briat et al., 2020; Naumann et al., 2020). Fertilisation directly impacts plant productivity by meeting nutrient requirements and applying supplementary chemical fertilisers (Barlog et al., 2022). PTPN 7 Unit Pagar Alam uses NPK fertiliser for plant roots and Bayfolan liquid fertiliser for leaves, both of which contain macronutrients and Cd. Contamination of soil with Cd can impede plant growth and damage their physiological and biological functions, so it's important to consider the potential negative impact on the environment when implementing these initiatives (Kiran et al., 2021). Roots can absorb cadmium through water mobilisation, nutrient uptake, and other dissolved compounds (Pasricha et al., 2021). Unregulated chemical application, such as Cd contamination, can lead to environmental pollution in industries that use heavy metal-containing compounds without ensuring safety (Bracher et al., 2021; Sabet et al., 2020).

PTPN 7 Unit Pagar Alam, a tea enterprise established in 1929, was under ongoing monitoring because cadmium was accumulating in its roots and leaves as a result of inorganic fertilisers. We are using phytoremediation, a biological process similar to planting, to mitigate Cd contamination and restore polluted soil (Bhat et al., 2022; Raza et al., 2020). Magnetic biochar is a cost-effective and environmentally friendly method for bioremediation; it enhances soil structure and reduces the presence of cadmium in soil (Lin et al., 2022). The addition of organic matter can decrease the soil's cadmium accumulation and its uptake by plants (Alam et al., 2020).

The high toxicity and resistance to degradation of Cd, which accumulates in tea, pose a significant risk to its health (Tan et al., 2022). New studies suggest that consuming Cd can lead to cancer cell formation and chronic disorders in humans through epigenetic modifications in mammalian cells (Genchi et al., 2020). Abd Elnabi et al. (2023) Bioremediation is a proven method for reducing heavy metals in soil, but research on direct reduction in plants, including tea, is limited. The objective of this research was to evaluate the impact of routine pruning on Cd accumulation in tea, as data on the presence of heavy metals in roots and leaves is scarce.

MATERIALS AND METHODS

Research Location

This study was conducted on a tea plantation owned by PTPN 7 Pagar Alam Unit, South Sumatra. The plantation area covers ±1,523 hectares, which was divided into five management divisions. The research location was mapped using a 1:20,000 scale map in accordance (Ginting et al., 2015). The condition of the plantation, including the history of land clearing, area size, tea variety, and plant age, was obtained through field surveys and interviews with plantation managers.

Methodology

The method used was a comprehensive survey with stratified sampling techniques based on the age class of tea plants. Sampling points were determined using the Global Positioning System (GPS), and then each point was assigned three replicates in accordance with (Chaudhuri et al., 2007).

The samples taken consisted of roots, leaves, and soil. A total of 12 root samples, 12 leaf samples, and 12 soil samples were obtained from 12 different locations. At each location, sampling was carried out at five sampling points, then composited into one composite sample for each type of material (roots, leaves, and soil). Soil samples were taken at a depth of 0–30 cm, while leaf and root samples were taken from tea plants at the same location.

Table 1. Sampling of roots, leaves, and soil based on plant age

Sample	Plant Age (year)				Block (ha)				∑ Sample		
	R1	R2	R3	R4	R1	R2	R3	R4	Root	Leaves	Soil
T1	14	20	34	37	1.5	11.7	15.7	7.2	20	20	20
T2	14	20	33	37	4.5	3.3	8.2	4.1	20	20	20
T3	14	21	33	37	8.2	7	5	10	20	20	20
∑ Composite Sample									12	12	12

Note: T1= Test 1, R1= Plant Age (4–14 year), R4= Plant Age (37–47 year, T2= Test 2, R2= Plant Age (15–25 year), T3= Test 3, R3= Plant Age (26–36 year)

Procedure Analysis Cadmium

Soil samples were first air-dried, sieved thru a 2 mm diameter sieve, and then their chemical properties were analyzed. pH analysis was performed using the potentiometric method (glass electrode) in a soil: water suspension at a ratio of 1:2.5. Organic carbon content was analyzed using the Walkley-Black method, while total nitrogen was determined using the Kjeldahl method. The heavy metal content (e.g., Pb, Cd, and Cu) in the soil was determined thru wet digestion using a mixture of HNO_3-$HClO_4$ acids, followed by measurement using an Atomic Absorption Spectrophotometer (AAS).

Leaf and root samples were first washed with distilled water, dried in an oven at 70 °C until constant weight, and then finely ground. Heavy metal analysis in plant tissues was also performed thru wet digestion using a mixture of concentrated acids, followed by metal content measurement using AAS.

Data Analysis

The data obtained from field surveys and laboratory analyses were processed descriptively. Next, analysis of variance (ANOVA) was performed to determine the effect of plant age on heavy metal accumulation in plant tissues. The results of the analysis were presented in tables and descriptive narratives to reinforce the discussion.

RESULT

Absorption of Heavy Metal Cadmium (Cd) in Leaves Per Plant

Based on the research that had been conducted by analysing the absorption of Cd content in tea leaves per tea plant, the results of the heavy metal absorption (Table 2).

Based on Table 2, the absorption of the heavy metal Cd in tea plant leaves at various age ranges of the plants was identified, showing that the lowest heavy metal absorption was found in leaf samples from plants aged 15–25 years or an average plant age of 20 years (Table 1), which means the age of the plant leaves was 1 year after the production pruning.

Cd concentrations in The Roots and Leaves of Tea Vary According to Age Range

The research assessing the cadmium concentration in tea plant roots and leaf samples, categorised by age range, was presented in Table 3, which displays the heavy metal content resulted.

Table 2. Results of heavy metal cadmium (Cd) absorption analysis in tea plant leaves

Results of Cadmium Heavy Metal Absorption Analysis	
Plant Age 5–15 years	Leaves Tea Plant (mg)*
T_1R_1	0.013
T_2R_1	0.004
T_3R_1	0.011
Average ± Standard Deviation	0.009 ± 0.004
Plant Age 15–25 years	Leaves Tea Plant (mg)*
T_1R_2	0.008
T_2R_2	0.002
T_3R_2	0.004
Average ± Standard Deviation	0.005 ± 0.002
Plant Age 25–35 years	Leaves Tea Plant (mg)*
T_1R_3	0.006
T_2R_3	0.013
T_3R_3	0.004
Average ± Standard Deviation	0.007 ± 0.004
Plant Age 35–45 years	Leaves Tea Plant (mg)*
T_1R_4	0.008
T_2R_4	0.008
T_3R_4	0.004
Average ± Standard Deviation	0.007 ± 0.004

Note: *) Analysis Results from PT Global Quality Analytical Laboratory.

Based on Table 3 above, the research results show that the analysis of Cd content in tea plant leaves was highest in leaf samples aged 4–14 years, with an average of 0.014 ± 0.007 mg/kg. Meanwhile, for the root samples, the highest Cd content was found in the 15–25 years and 37–47 years age groups, with a difference of 0.001 mg/kg. In the age range of 15–25 years, the average Cd content was 0.016 ± 0.004 mg/kg, while in the age range of 37–47 years, it was 0.015 ± 0.004 mg/kg (Table 4). Based on the results of the Anova test above, it could be seen that the calculated F for the treatment was 9.68, which was greater than the 5% table F (4.757), indicating that the treatment is significantly different or had a significant effect on Root Metal Absorption. Because the treatments were significantly different, further testing was conducted using the BNJ test with the following results (Table 5).

Table 3. Results of Cd content analysis in tea roots and leaves by age range

Results of Analysis Cadmium		
Plant Age 4–14 Years	Root Tea Plant (mg/kg)	Leaves Tea Plant (mg/kg)
ST1R1	0.012	0.019
ST2R1	0.012	0.006
ST3R1	0.013	0.016
Threshold**	1	1
Average ± Standard Deviation	0.012 ± 0.001	0.014 ± 0.007
Plant Age 15–25 Years	Root Tea Plant (mg/kg)	Leaves Tea Plant (mg/kg)
ST1R2	0.019	0.012
ST2R2	0.018	0.004
ST3R2	0.012	0.006
Threshold **	1	1
Average ± Standard Deviation	0.016 ± 0.004	0.007 ± 0.004
Plant Age 26–36 Years	Root Tea Plant (mg/kg)	Leaves Tea Plant (mg/kg)
ST1R3	0.006	0.009
ST2R3	0.006	0.019
ST3R3	0.006	0.006
Threshold **	1	1
Average ± Standard Deviation	0.006 ± 0	0.011 ± 0.007
Plant Age 37–47 Years	Root Tea Plant (mg/kg)	Leaves Tea Plant (mg/kg)
ST1R4	0.019	0.012
ST2R4	0.012	0.012
ST3R4	0.014	0.007
Threshold **	1	1
Average ± Standard Deviation	0.015 ± 0.004	0.010 ± 0.003

Note: *) Analysis Results from the Laboratory of PT Global Quality Analytical, **) A Case Study from Puan County, Guizhou Province, China (2018).

Table 4. Results of ANOVA test on cadmium (Cd) content across plant age ranges

Parameters	F Count	F Table		Explanation
		5%	1%	
Akar	9.680851*	4.757063	9.779538	**
Daun	0.650279*	4.757063	9.779538	ns

Note: *) ANOVA test results, (**) Clearly different, ns= Not significantly different

Table 5. Results of ANOVA Test on Cadmium (Cd) absorption in leaves across plant age ranges

Parameters	F Count	F Table		Explanation
		5%	1%	
Absorption Leaves	0.643099*	4.757063	9.779538	ns

Note: *) ANOVA test results, ns = Not significantly different

DISCUSSION

The results of the ANOVA test show that the age of the plants does not significantly affect the absorption of Cd in tea leaves, as the leaves naturally fall off with age. Additionally, leaves can fall off due to environmental variables, including temperature and drought (Estiarte & Peñuelas, 2015). Factors that influence the variation in heavy metal content in plants include the age of the plant. The ANOVA test findings indicate that the age of the plant significantly affects the deposition of Cd in the roots. The absorption of metals by the roots is greater in older plants, supported by other research indicating that plant age affects light tolerance and tissue integrity. As a result, as the plants mature, both the efficiency and the rate of photosynthesis will increase (Bielczynski et al., 2017). According to Irawati and Widodo (2017), when the plants mature, the number of leaves will increase, thereby enhancing the photosynthesis process. The age of the plant affects metal absorption (Natsir et al., 2019).

The treatment given to the plants can affect their heavy metal accumulation (Shahid et al., 2017). Like plant pruning, which can affect Cd absorption, as illustrated in Table 2, showing that minimal Cd absorption was observed in leaf samples aged 15–25 years, with the post-pruning leaf age being only 1 year. This indicates that pruning can affect metal absorption in plants. Plant leaves can absorb metals; however, the amount varies depending on the type of tissue and treatment applied (Hidayati, 2005). This evidence shows that pruning can reduce both the surface area and the number of leaves, thereby decreasing the transpiration rate of the plant.

The reduction in transpiration will affect the volume of water absorbed by the roots. As a result, pruning can also reduce the absorption of heavy metals found in the soil (Sari & Sulistiani, 2017). According to the research by Widowati et al. (2016), proper harvesting time and strict pruning can reduce heavy metal absorption in plants. According to Zhang et al. (2018), the standard threshold for tea plants is 1.0 mg/kg, with Cd accumulation in the roots being much greater in older plants, while the largest accumulation in leaf samples occurs in younger plants. This conclusion indicates that although the absorption of Cd in the leaves does not substantially affect the age of the plant, the age of the leaves does influence the accumulation of Cd. The concentration of Cd in the root and leaf samples of tea plants at PTPN 7 Unit Pagar Alam remains low across all age ranges. The accumulation of various amounts of heavy metals in plants depends on their exposure to contaminated soil and their age (Naser et al., 2011).

CONCLUSSION

Based on the research conducted, it can be concluded that the Cd content in tea plants at PTPN 7 Unit Pagar Alam has an average heavy metal content in the leaves of 0.010 ± 0.005 mg/kg and in the roots of 0.012 ± 0.004 mg/kg. The heavy metals are still below the normal threshold for heavy metal content in tea plants, which is 1.0 mg/kg, making them safe for human and animal consumption. In addition, pruning tea plants affects the absorption of Cd in tea leaves. However, the age of the plants does not significantly affect the accumulation of heavy metals in the tea leaves.

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