Malaysian Journal of Soil Science 2025 Vol. 29: 427-440

Heavy Metal(loid)s Accumulation of *Pteris vittata* L. Populations and Their Association with Soil Edaphic Factor

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ABSTRACT

Pteris vittata L. is a well-known As-hyperaccumulator that can accumulate more than 1000 μg g^{-1} of As. Research on the effect of edaphic influences on the heavy metal(loid)s (HMs) accumulation of P. vittata is unknown and less reported. The heavy metal uptake in plants may be influenced by exogenous factors of soil, such as pH, electrical conductivity (EC), cation exchange capacity (CEC), etc. This study aims to investigate the association between the heavy metal(loid)s' accumulation of wild P. vittata populations with the soil physicochemical properties. The samples of fronds were collected randomly from five different habitats and oven-dried; meanwhile, soil samples were air-dried and processed before undergoing further digestion analyses. The N concentrations was analysed using the Kjedahl method while P, K, Ca, Mg, As, Cd, Pb and Cr were analysed using ICP-OES. Soil analyses also involved nutrients and heavy metals analysis with the physicochemical (pH, CEC, EC and soil texture). The results showed that the highest HMs accumulation of P. vittata was As with 1380 ± 140 mg kg^{-1}, Cd at 41.9 ± 4.19 mg kg^{-1}, Pb at 7.57 ± 3.68 mg kg^{-1} and Cr at 3.33 ± 0.57 mg kg^{-1}. Among the HMs observed, only Pb had significant differences among P. vittata populations ($p<0.05$) while other HMs (As, Cd, Cr) were insignificant ($p>0.05$). Based on the Pearson correlation coefficient (r), there was a negative correlation of foliar As and foliar Cd with soil Cd ($p<0.05$). However, there was no correlation between the foliar HMs with other soil physicochemical properties ($p>0.05$). We conclude that wild P. vittata can absorb high concentrations of As but this uptake was uncoupled with the high concentrations of HMs in the soil. Further research is required to investigate the potential of HMs accumulation in P. vittata and the effect of HMs applications on the growth and physiology of P. vittata under controlled environments.

Keywords: **Arsenic hyperaccumulator**, **heavy metal(loid)s**, **soil physicochemical**, ***Pteris vittata***

INTRODUCTION

Heavy metal(loid)s (HMs) is a major source of environmental contamination, which results from natural phenomena and anthropogenic activities and due to their non-biodegradability, they remain persistent in the environment (Ejaz *et al*., 2023). Since HMs cannot undergo microbial and chemical degradation in soil, they become a risk to the ecosystem by direct ingestion, plant uptake, which is toxic to the plant and also the food chain, decreases soil fertility and contaminates water sources (Briffa *et al*., 2020). Plants can be used to accumulate HMs from contaminated soil and some plants, have a high capacity to accumulate HMs, are usually referred to as hyperaccumulators(Gavrilescu, 2022). It was reported that more than 700 species were considered metal hyperaccumulators in 2017 (Reeves *et al*., 2017) and among the hyperaccumulators are *Brassica juncea* (Indian mustard) (Chaudhry *et al*., 2020), *Melastoma malabathricum* (Mahmud & Burslem 2020; Mahmud *et al*., 2024; Saberi *et al*., 2024), *Youngia* (Lin et al., 2015), *Chrysopogon zizanioides* (Vetiver grass) (Chintani *et al*., 2021), *Dendrocalamus asper* (Syazwani *et al*., 2024) and *Pteris vittata* (Kohda *et al*., 2022). These hyperaccumulator plants can help in the phytoremediation process of cleaning the environment from heavy metal(loid)s.

Pteris vittata, commonly known as the Chinese brake, Chinese ladder brake, or simply ladder brake, is one of the fern species in the Pteridoideae subfamily of the Pteridaceae (Martínez & Vilte, 2012). *P. vittata* is known for its ability to hyperaccumulate As and this unique trait has led to its recognition as a potential tool for phytoremediation, which is the use of plants to clean up contaminated soil or water. It can accumulate up to 22 mg g^{-1} As in the frond dry weight, although phytotoxicity occurs when shoot arsenic is larger than about 10,000 mg kg^{-1} (Zhang *et al*., 2002). For medicine, *P. vittata* is high in phenolic and flavonoid, which are both good antioxidants (Singh *et al*., 2015). There is also an experiment in exploring the use of *P. vittata*'s extract as a wound treatment (Paul *et al*., 2020).

The edaphic factor consists of the physical, chemical and biological properties of soil, which result from natural or anthropogenic activities and both chemical and physical properties of soil can influence the ecology and evolution of plants and their related biota (Murdiono *et al*., 2025;Rajakaruna *et al*., 2019). The accumulation of HMs in soil can be influenced by soil properties, including soil organic matter (SOM), pH, cation exchange capacity, soil texture, bioavailability of nutrients, etc (Amirah *et al*., 2023; Chukwu & Gulser, 2025). For example, the low soil pH can dependently cause an increase in heavy metals accumulation in plants (Zn, Cd, and Pb) (Clemente *et al*., 2005). Some heavy metal, such as Cr which has an association with the soil pH and EC that relate to the acidity and salinity of soil (Zarcinas *et al*., 2004).

In Malaysia, studies on HMs accumulation by *Pteris vittata* grown at in-situ or ex-situ was less reported and only reported by Ashraf *et al*. (2011). Research on the association of soil edaphic factors and the effect of metal additions on the metal hyperaccumulation and physiology of *P. vittata* is unknown and require further investigation. The research questions arising from this study were does the accumulation of HMs in *Pteris vittata* L. vary among populations? and is this variation related to soil heavy metal(loid)s concentrations? This experiment was conducted with two main objectives, which are 1) to investigate the concentration of foliar heavy metals collected from different populations and habitats and 2) to determine the association between soil physicochemical properties and the HMs concentration with the foliar heavy metals' accumulation in the *P. vittata* population.

MATERIALS AND METHODS

Plant and soil samplings

The fronds (leaflets) of *Pteris vittata* (**Figure 1**) were collected randomly from five different habitats, which included roadside, industrial, agricultural, post-mining, and wetland (**Table 1**). Four to six undamaged fronds from each location were collected and formed into 3 replicates per location. Fronds were then washed with distilled water, air-dried for at least 4 hours, and then dried again using an oven with a temperature of 60°C for at least 3 days (Tu & Ma, 2003; Yu *et al*., 2020). Three soil samples will be taken from 0 to 15 cm depth using a soil auger, 1–2m distance from each individual of the *P. vittata* population, following Mahmud & Burslem (2018). The soil samples were air-dried at room temperature for at least a week. Then, the samples were ground with a mortar and pestle and then sieved using size 2 mm and 60 mesh sieves before conducting the physicochemical analysis of the soil properties.

Table 1. Sampling location of *P. vittata*

Habitat	Label	Location/ Coordinate
Roadside area	S1	Bangi/ 2°56’42” N 101°45’52” E
	S2	Elmina/ 3°10’29.7” N 101°30’54.3” E
Industrial area	S3	Bangi/ 2°57’53” N 101°44’49” E
	S4	Balakong/ 3°00’47” N 101°44’34” E
Agricultural area	S5	Shah Alam/ 3°05'35.1” N 101°31'08.1” E
Post-mining	S6	Kuang/ 3°14’49” N 101°31’40” E
Wetland	S7	Presint12/ 2°57’37” N 101°42’26” E

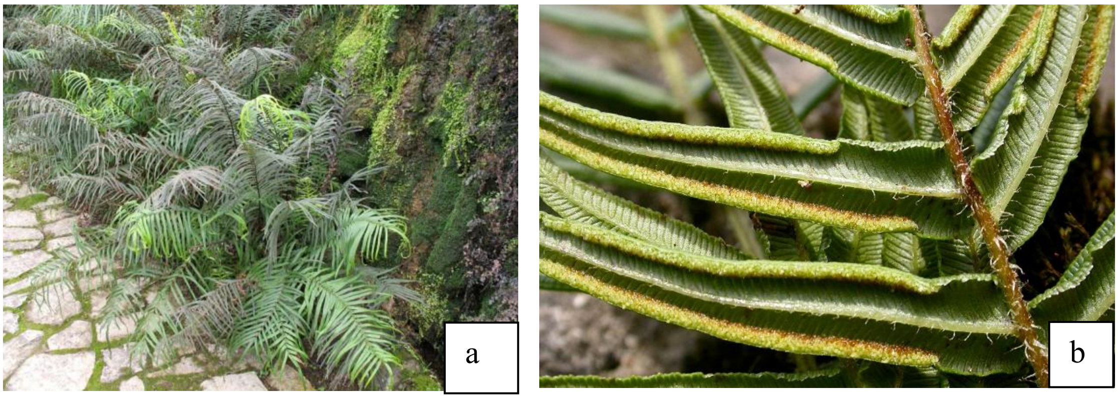

Figure 1. *Pteris vittata* L. in wild population. (a) The frond of *P. vittata* (b) Sori of *P. vittata*

Nutrients and heavy metal(loid)s analysis

The dry ashing technique was used to digest the plant materials before proceeding to analyse the elements (Khairil *et al*., 2014; 2015; Sahrawat *et al*., 2002). The dried and ground plant materials were weighed, 0.5 g into 30mL silica crucibles. The crucibles were placed in a muffle furnace which was set at 470℃, and the temperature was gradually raised. The plant samples were ashed for 16 h by leaving them overnight. The cooled crucibles were taken out and the ash was moistened with a few drops of water, followed by 3 mL of 5 M hydrochloric acid. The contents were heated on a hot plate at about 80℃ to dissolve the ash and then the digested plant samples were analyzed for P, K, Ca, Mg, As, Cd, Pb, and Cr using ICP-OES (CIROS, Spectro Analytical Instruments, Germany). The total nitrogen content (% N) was extracted using the Kjeldahl method, followed by identification through distillation and titration with 0.01N HCl.

The soil samples were prepared with 0.5 g dried soil digested using 10 mL aqua regia (3:1 conc. HCl:HNO_3) and filled up to 50 mL with deionized water for chemical analysis, following Antoniadis *et al*. (2021). The chemical contents, which were P, K, Ca, Mg, As, Cd, Pb, and Cr were analyzed using ICP-OES (CIROS, Spectro Analytical Instruments, Germany). The total nitrogen content (% N) was extracted using the Kjeldahl method, followed by identification through distillation and titration with 0.01 N HCl. Besides, soil physical properties were analyzed to have details information on the physicochemical properties of the soils at each population area. The pH was measured with a ratio of 1:2.5 of soil to water and the pH reading was done using a calibrated Beckman Digital pH meter (Rayment & Lyons, 2010). The cation exchange capacity (CEC) was determined using the leachate method and measured after the final extraction (third leachate) using 1 M ammonium acetate (NH_4-OAc) adjusted to pH 7.0 and determined with titration of 0.01N HCl. Electrical conductivity (EC) was measured using an EC-Meter (Ion Check 65, Radiometer Analytical), with the ratio of soil to water being 1:5 (He *et al*., 2012). The determination of soil organic matter (%) was determined by loss of weight on ignition (LOI) technique, followed Zineb *et al*. (2023) which involved the soil being heated in the oven for 16 hours at 105℃ to remove excess moisture (pre-ignition) and reheated for another 6 hours at 550°C (post-ignition). The sample was left to cool and weighed after every ignition. The percentage from the LOI was calculated using the equation below:

$$\%OM = \frac{(Pre - ignition\ weight, g) - (Post - ignation\ weight, g)}{Pre - ignation\ weight, g} \times 100$$

Particle size analysis was used to determine the soil texture consists of the percentage of sand, silt, and clay, followed Teh & Talib (2006). The percentage of each soil texture was determined using the pipette method which separated the soil particles and the results were compared to the soil classification scheme (**Figure 2**).

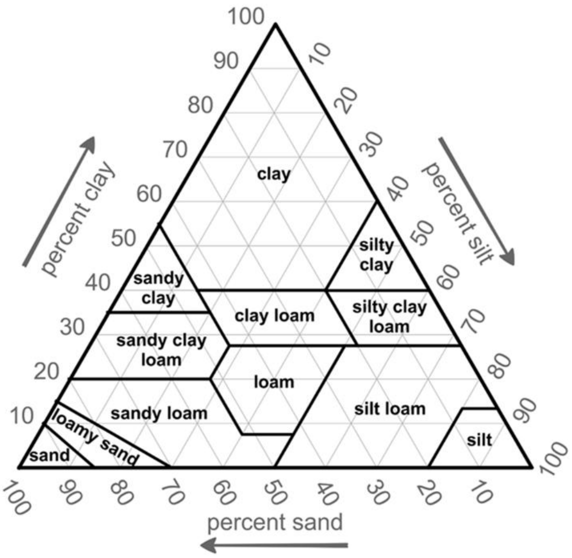

Figure 2. The soil classification scheme by the USDA (Groenendyk et al., 2015)

Statistical analysis

The data analysed was calculated and expressed as mean and standard error (SE) and subjected to an ANOVA using R-studio (v.1.0.3). A Pearson correlation test was done to define the relationship between foliar nutrients and soil heavy metal concentration. The association of foliar nutrients and heavy metals/metalloid elements was identified using Principal Component Analysis (PCA). The significance level was set at a 95% confidence level (α=0.05). All analytical results were conducted in an average of three replicates.

RESULTS AND DISCUSSION

Foliar nutrients and heavy metal(loid)s concentrations

The mean foliar nutrient and heavy metal(loid)s concentrations of *P. vittata* in wild populations were presented in **Table 2**. Significant differences were observed in the concentrations of P, K, Ca, and Mg among the population. The highest N (%) was found at site S4 (industrial area) with 5.5 ± 0.18% in the industrial area. The S1 (roadside) population contributed the highest P (9.04 ± 2.51 mg g^{-1}) and Ca (6.24 ± 0.58 mg g^{-1}). For the K element, S2 was the highest at 19.24 ± 1.46 mg g^{-1}; meanwhile, the Mg element was the highest (1.58 ± 0.14 mg g^{-1}) at S3. Among the HMs, the average of As concentration was the highest compared to Cd, Pb and Cr. The highest accumulation of As was found at S2 (1.38 ± 0.14 mg g^{-1}) and the lowest at S3 (industrial area) (0.08 ± 0.01 mg g^{-1}). The Cd concentration was the highest at S2 (41.9 ± 4.19

mg kg^{-1}) and the lowest at S3 (2.83 ± 0.17 mg kg^{-1}). The highest Pb and Cr concentrations were observed at S4 (industrial rea), at 7.57 ± 3.68 mg kg^{-1} and 3.33 ± 0.57 mg kg^{-1}, respectively.

P. vittata accumulates As derived from the As compounds into its fronds (136–315 p.p.m) at levels 3–6 times greater than soil arsenic (Ma *et al*., 2001). The result indicated that *Pteris vittata* could accumulate relatively high As at its natural state and potentially accumulate other metal elements. Several reports found that *P. vittata* could accumulate more than 300 mg kg^{-1} As and 250 mg kg^{-1} Pb in the ex-mining area at the frond (Ashraf et al., 2013), and 150 mg kg^{-1} Cd in the contaminated area (Xiao *et al*., 2008). Oliveira *et al*. (2014) stated that *P. vittata* accumulated 234 mg kg^{-1} at the frond with the application of 0.05 mM CrVI (chromate). This study confirmed that high As accumulation of *P. vittata* is in the frond part (1380 mg kg^{-1}; **Table 2**), which was a thousand times more than arsenic soil (1.13 mg As kg^{-1}; **Table 4**). But, the Cd, Pb and Cr were less taken up when growing in the wild population (non-contaminated) compared to the contaminated area.

The correlation of elements showed there was a significant positive correlation (p<0.01) among foliar metal concentrations **(Table 3**). For N concentration, there was a significant correlation with heavy metal concentrations, Pb and Cr. The P concentrations had a significantly positive correlation with other nutrients, K, Ca, and Mg, and heavy metal, Cr. The K concentration showed a significant correlation with Ca, Mg, Pb, and Cr concentrations. The Mg concentration was positively correlated with Pb and Cr concentrations (p<0.05).

Focusing on the correlation among HMs concentrations, As shows a strong association with Cd (p<0.05), which means the higher As uptake may increase the Cd concentrations. This result was dissimilar to Cao et al. (2025) as they reported that the uptake of As and Cd by ryegrass showed opposite effects on each other when applied with As and Cd applications and resulting in toxicity to ryegrass. There was also a significant interaction between Pb and Cr accumulation with nutrients (**Table 3**). According to Saleem *et al*. (2022), high concentrations of Cr could lead to nutrient deficiency. However, according to Cao et al. (2025) and Lin *et al*. (2010), these effects vary among plant hyperaccumulators since they have different responses and tolerance to HMs.

Table 2. The mean (± SE) foliar nutrient and heavy metal(loid)s concentrations of *P. vittata* among seven populations

Population	N (%)	P (mg/g)	K (mg/g)	Ca (mg/g)	Mg (mg/g)	As (mg/kg)	Cd (mg/kg)	Pb (mg/kg)	Cr (mg/kg)
S1	1.6±0.25	9.04±2.51	17.63±1.9	6.24±0.58	1.29±0.1	170.11±90	5.67±2.5	2.53±0.22	2.67±0.03
S2	1.13±0.7	4.25±0.29	19.24±1.46	3.05±0.25	0.95±0.12	1380.12±110	41.90±4.19	1.32±0.51	2.31±0.15
S3	1.63±0.56	3.23±0.68	17.75±2.88	5.56±0.2	1.58±0.14	80.01±10	2.83±0.17	3.83±2.04	2.57±0.15
S4	5.51±1	5.44±1.55	18.05±1.42	3.41±0.35	1.45±0.12	220.11±98	7.31±3.37	7.57±3.68	3.33±0.57
S5	1.62±0.39	1.04±0.03	7.74±0.41	2.11±0.02	0.81±0.08	110.12±70	3.50±2.02	1.17±0.3	1.13±0.12
S6	0.87±0.03	2.58±0.28	8.54±1.32	1.77±0.22	0.68±0.04	440.10±101	12.97±3.33	0.73±0.38	1.27±0.07
S7	2.23±1.27	1.41±0.06	8.29±0.03	1.81±0.03	0.56±0.03	250.07±30	7.47±0.9	1±0.21	1.52±0.25
F-value	0.05	15.55	11.23	38.17	16.34	1.32	1.6	10.25	0.68
p-value	0.83	0.000***	0.000***	0.000***	0.000***	0.27	0.22	0.00**	0.42

Notes: p<0.05*, p<0.01** and p<0.001***; The locations of the sampling site can be referred in Table 1.

Table 3. The Pearson correlation coefficient (r) between foliar nutrient and heavy metal(loid)s elements of *P. vittata* among seven populations

	N	P	K	Ca	Mg	As	Cd	Pb
P	0.22							
K	0.24	0.71***						
Ca	0.03	0.63**	0.66***					
Mg	0.3	0.49*	0.74***	0.8***				
As	-0.21	0.06	0.32	-0.19	-0.2			
Cd	-0.2	0.08	0.34	-0.17	-0.18	1.0***		
Pb	0.66***	0.33	0.43*	0.34	0.6**	-0.18	-0.17	
Cr	0.48*	0.45*	0.72***	0.65***	0.79***	0.01	0.03	0.71***

Notes: p<0.05*, p<0.01** and p<0.001***

Soil nutrient and heavy metal(loid)s concentration and their association with foliar heavy metal(loid)s concentrations

The mean concentration of different soil minerals and heavy metal(loid)s showed that S4 (industrial area) had the highest amount of soil N (0.46 ± 0.13%), P (0.92 ± 0.4 mg g^{-1}), and Mg (0.54 ± 5.0.23 mg g^{-1}) (**Table 4**). For K and Ca, the highest concentration was at S2 (1.38 ± 0.07 mg g^{-1}) and S5 (agricultural site) (13.18 ± 5.22 mg g^{-1}. The highest As, Cd, and Pb were recorded at S1 (roadside), 33.59 ± 17.64 mg As kg^{-1}, 1.47 ± 0.49 mg Cd kg^{-1}, and 35.29 ± 11.99 mg Pb kg^{-1}, whereas the highest Cr was in S6 (post mining) with 35.01 ± 7.4 mg Cr kg^{-1}. Besides, only the concentration of element K showed significant differences among populations. The correlation between elements in soil showed N had a positive correlation with P and Pb, while concentrations of P had a significant positive correlation with Pb (**Table 5**). The K concentration showed a significant negative correlation with As and Cd concentrations. Ca element was positively significantly related to Mg and negatively correlated with As (p<0.05).

The soil pH among the populations was acidic, ranging from 3.98 to 6.17. The S3 and S4 populations had the most acidic soil with 3.98 ± 0.09 and 4.66 ± 0.18, respectively. The result for EC (electric conductivity) shows the range was between 3.63 to 8.88 d Sm^{-1}, and the highest EC value was the S7 population at 8.8±0.44 d Sm^{-1}. The percentage of soil organic matter ranged from 2.73% to 7.69% and the highest amount of soil organic matter (SOM) was S5 (7.69 ± 0.2%). The CEC value ranged from 21.2 to 42.57 cmol($^{+}$) kg^{-1} and S5 was the highest at 42.57 ± 10.12 cmol($^{+}$) kg^{-1} (Table 6). There were significant differences for sand, silt, clay, pH, EC and SOM across the population (p<0.05). The PCA explained 76.63% of the cumulative variance of the data set for the first four PC axes (Table 8). The PCA of the soil elements and physicochemical (**Figure 3**) showed that high EC is intercorrelated with the soil P, Ca, Mg and Pb concentrations.

The increase in pH in acidic soils happens together with the reduction and a decrease in pH occurs in the oxidation process (Sintorini *et al*., 2021). As the pH is escalating, the mobility of heavy metals is deescalating, with a sequence of Cd > Zn > Ni > Cu > Pb. At pH 7, Zn and Cd ions begin to break free of their compounds; meanwhile, Cd, Co, and Cr, as less mobile metals, will begin to dissolve at pH<5 (Sintorini *et al*., 2021). Saline soils are those that have an electrical conductivity of the saturation soil extract of more than 4 dS m^{-1} at 25°C. High salinity affects the soil fertility negatively by osmotic stress, decreased water availability, and ionic stress, which leads to deficiency and/or toxicity of some nutrients (Ehtaiwesh, 2022). The SOM had an abundance of organic molecules that can retain HMs more when humified (Chukwu & Gulser, 2025). The cation exchange capacity (CEC) is the ability of a soil to adsorb and exchange mineral ions that are essential for plant growth and high percentages of clay and/or silt particles generally have a high CEC (Rajakaruna *et al*., 2019).

The soil Cd concentrations showed negative and moderate intercorrelation with foliar As and Cd (r<0.4) (**Table 7**). Meanwhile, the foliar Pb had a positive correlation with soil N and P. The soil nutrient K had a moderate correlation with the As and Cd of foliar uptake. Overall, there was no significant association between the soil HMs concentrations with the foliar metal concentrations. This indicates the higher amount of foliar metal concentrations, such as As and Cd in the soil, did not reflect the higher concentrations of HMs in the *P. vittata*. This result is similar to Mahmud & Burslem (2018) and Metali *et al*. (2012), where they reported that the metal accumulation in metal hyperaccumulator is non associated with the soil metal elements. According to Metali *et al*. (2012) the accumulation trait in metal hyperaccumulator is phylogenetic and is not affected by the metal elements in the soil.

Table 4. The mean (±SE) soil nutrient and metal concentrations of *P. vittata* among seven populations

Population	N (%)	P (mg g^{-1})	K (mg g^{-1})	Ca (mg g^{-1})	Mg (mg g^{-1})	As (mg kg^{-1})	Cd (mg kg^{-1})	Pb (mg kg^{-1})	Cr (mg kg^{-1})
S1	0.22±0.04	0.45±0.14	0.59±0.03	2.19±0.2	0.54±0.13	33.59±17.64	1.47±0.49	35.29±11.99	28.23±8.96
S2	0.07±0.23	0.20±0.05	1.37±0.07	2.31±0.81	0.54±0.07	1.13±0.61	0.35±0.04	10.57±1.06	20.83±2.4
S3	0.23±0.08	0.38±0.14	0.87±0.03	1.75±0.54	0.43±0.17	8.91±4.97	0.64±0.1	23.83±2.81	13.35±2.28
S4	0.46±0.13	0.92±0.4	0.7±.0.01	3.27±1.22	0.54±0.23	22.07±17.39	0.97±0.3	29.91±9.6	26.27±8.21
S5	0.21±0.06	0.64±0.4	1.04±0.15	13.18±5.22	3.45±0.15	15.01±7.1	0.97±0.31	15.81±2.53	20.4±4.63
S6	0.12±0.01	0.36±0.17	0.66±0.3	4.69±3.49	0.62±0.27	30.76±13.36	1.32±0.22	7.41±5.17	35.01±7.4
S7	0.15±0.04	0.13±0.04	0.97±0.04	1.17±0.06	0.22±0	21.47±7.03	0.88±0.12	13.57±1.73	29.23±5.22
F-value	0.09	0.09	4.15	0.64	0.42	0.22	0.1	2.7	1.35
p-value	0.77	0.76	0.01**	0.43	0.53	0.64	0.76	0.06	0.3

Notes: p<0.05*, p<0.01** and p<0.001***

Table 5. The Pearson correlation coefficient (r) between soil heavy metal(loid)s and nutrient elements among seven *P. vittata* populations

	N	P	K	Ca	Mg	As	Cd	Pb	Cr
P	0.69***								
K	-0.26	-0.16							
Ca	0.03	0.1	0.14						
Mg	0.1	0.32	0.25	0.74***					
As	-0.15	-0.16	-0.51*	-0.31	-0.19				
Cd	-0.10	0.02	-0.59**	-0.06	-0.05	0.91***			
Pb	0.63**	0.56**	-0.22	-0.01	-0.02	-0.3	-0.15		
Cr	0.04	-0.1	-0.34	-0.17	-0.22	0.48*	0.47*	-0.2	

Notes: p<0.05*, p<0.01** and p<0.001***

Table 6. The soil physical characteristics of *P. vittata* among seven populations

Location	Sand %	Silt %	Clay%	Texture class	pH	ECs (d Sm^{-1})	OM%	CEC (cmol($^{+}$) kg^{-1})
S1	56.67±0.88	14.33±2.33	29±1.53	Sandy clay loam	5.15±0.14	7.15±0.11	7.05±0.15	21.2±2.52
S2	52.33±1.76	16.33±2.03	31.33±0.33	Sandy clay loam	5.75±0.22	8.31±0.34	2.73±0.09	24.13±3.33
S3	45±1.73	15.33±2.33	39.67±2.33	Sandy clay	3.98±0.09	7.28±0.3	6.73±0.24	34.07±8.49
S4	26.67±2.19	43.67±2.4	29.67±0.33	Silty clay loam	4.66±0.18	8.41±0.15	3.65±0.14	30.63±1.56
S5	67.67±1.45	16.33±1.86	16±1	Sandy loam	6.17±0.03	3.63±0.17	7.69±0.2	42.57±10.12
S6	32.33±1.86	48.67±1.76	19±3.61	Loam	5.89±0.26	5.88±0.11	5.1±0.06	22±5.2
S7	50±1.73	37.33±1.45	12.67±0.33	Loam	5.31±0.15	8.8±0.44	5.72±0.19	28.07±2.52
F-value	68.66	54.55	29.62	-	20.65	48.18	124.33	0.01
p-value	0.000***	0.000***	0.000***	-	0.000***	0.000***	0.000***	0.91

Notes: $p<0.05$*, $p<0.01$** and $p<0.001$***

Table 7. Pearson correlation coefficient (r) between soil heavy metal(loid)s and nutrient elements with the foliar heavy metal(loid)s concentrations

Elements	Foliar As	Foliar Cd	Foliar Pb	Foliar Cr
Soil N	-0.346	-0.335	0.653***	0.384
Soil P	-0.14	-0.134	0.524**	0.145
Soil K	0.576**	0.573**	-0.201	-0.168
Soil Ca	-0.053	-0.062	-0.098	-0.338
Soil Mg	-0.174	-0.179	-0.073	-0.421
Soil As	-0.419	-0.422	-0.172	0.024
Soil Cd	-0.45*	-0.454*	-0.174	-0.063
Soil Pb	-0.23	-0.216	0.355	0.395
Soil Cr	-0.038	-0.044	-0.304	-0.307
		Soil PC axes		
Soil PC1	0.004	0.002	-0.44	-0.54
Soil PC2	0.64	0.65	-0.02	0.26

Notes $p<0.05$*, $p<0.01$**, $p<0.001$***

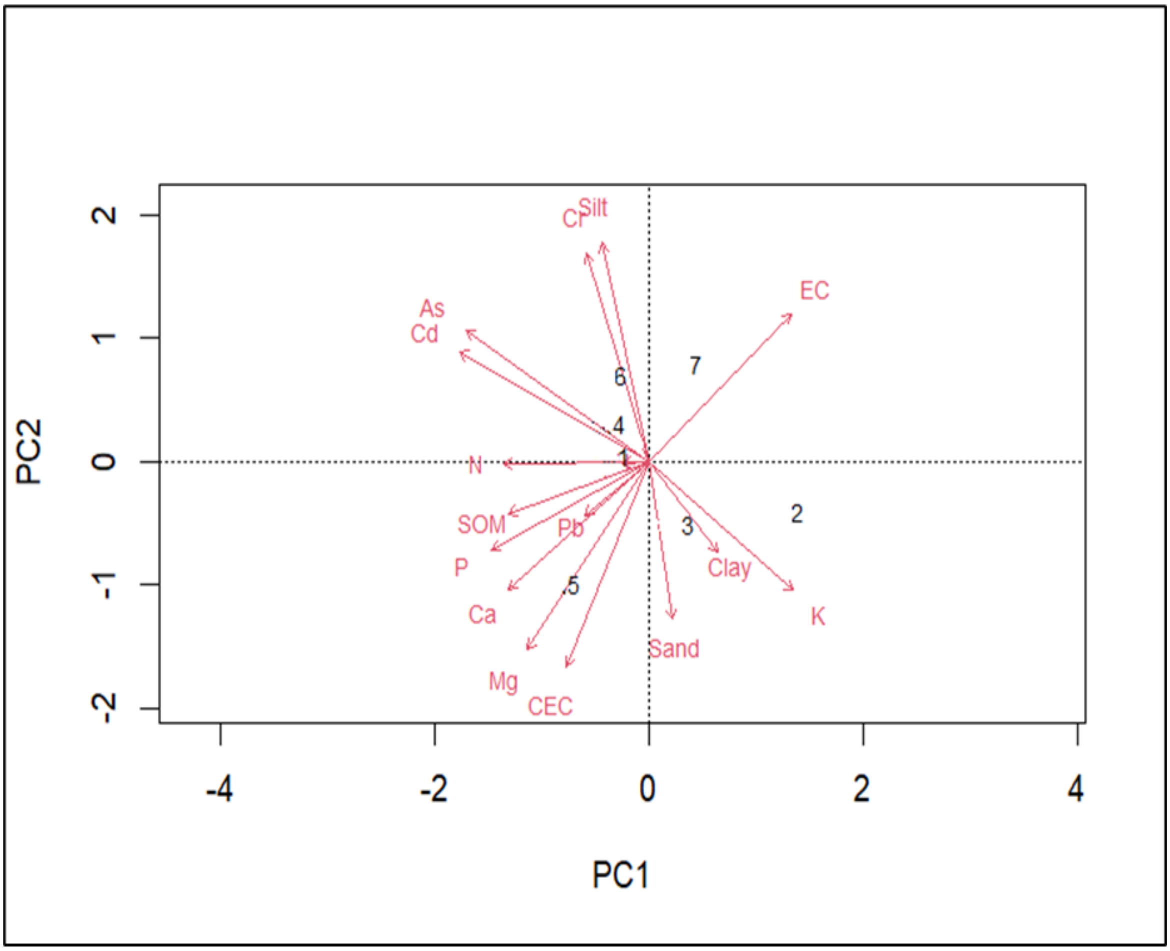

Figure 3. Biplot of scores for principal component axes (PC) 1 and 2 from the principal component analysis of 16 soil elements and physicochemical of the seven *Pteris vittata* populations.

Note: PC1 and PC2 accounted for 29.84% and 56.66% of the total variation, respectively. The arrows show the loading of each variable on the first two PC axes. [Notes: 1 (Roadside; Bangi), 2 (Roadside; Elmina), 3 (Industrial; Bangi), 4 (Industrial; Balakong), 5 (Agriculture; Shah Alam), 6 (Post-mining; Kuang) and 7 (Wetland; Presint12)]

Table 8. Summary statistics of PCA axes related to soil physicochemical elements

Importance of components	PC1	PC2	PC3	PC4
Eigenvalue	5.43	2.63	1.43	0.4
Percent of variance (%)	26.95	21.06	16.55	10.07
Cumulative variance (%)	26.94	48	64.56	76.63
Loadings of foliar properties				
Available N	0.1	0.26	**0.43**	0.24
Available P	-0.008	0.2	**0.42**	0.22
Available K	-0.21	0.19	-0.4	0.13
Available Ca	**-0.36**	-0.007	0.11	0.21
Available Mg	**-0.44**	0.002	0.17	0.13
Available As	0.14	**-0.42**	0.17	-0.21
Available Cd	0.07	**-0.41**	0.28	-0.21
Available Cr	0.15	**-0.34**	0.1	0.19
Available Pb	0.06	**0.32**	**0.36**	-0.04
pH	-0.28	-0.27	-0.19	0.26
EC	**0.38**	0.16	-0.21	-0.03
SOM	-0.25	-0.11	**0.32**	**-0.35**
CEC	-0.27	0.16	0.09	0.14
Sand	**-0.37**	-0.02	-0.07	**-0.33**
Silt	0.23	-0.2	0.06	0.52
Clay	0.17	**0.34**	0.007	**-0.33**

CONCLUSIONS

Pteris vittata accumulated high concentrations of As compared to other HMs Cd, Pb and Cr. There were no significant differences in the accumulation of HMs throughout the population of *P. vittata* in relation to the soil HMs concentrations. The soil HMs showed no contamination occurred, but *P. vittata* was still able to accumulate HMs, especially As. This result supports the findings of other previous researchers who reported that the metal accumulation in plants is a phylogenetic trait and is uncoupled from the soil metal elements. Future research can focus on evaluating the potential of *P. vittata* to accumulate higher concentrations of HMs when cultivated in a controlled environment. Understanding the potential of *P. vittata* in accumulating high concentrations of HMs may benefit the phytoremediation efforts in the future.

ACKNOWLEDGEMENTS

This research was funded by the UPM Putra Grant 2020 (GPM-IPM/2020/9690400).

REFERENCES

Amirah, S.S., Khairil, M., Murdiono, W.E., Halmi, M.I.E., Amalina, N.R., Yong, J.W.H., and Burslem, D.F.R.P. (2023) Edaphic influences on the nutrient concentrations and antioxidant activity of different tea clones (*Camellia sinensis* (O.) Kuntze) grown at the lowland tea plantation, Bukit Cheeding, Selangor, Malaysia. *Malaysian Journal of Soil Science* 2023 Vol. 27: 147-163. https://www.msss.com.my/mjss/Full%20Text/vol27/V27_12.pdf

Antoniadis, V., Shaheen, S. M., Stärk, H. J., Wennrich, R., Levizou, E., Merbach, I., & Rinklebe, J. (2021). Phytoremediation potential of twelve wild plant species for toxic elements in a contaminated soil. *Environment International*, *146*, 106233. https://doi.org/10.1016/j.envint.2020.106233

Ashraf, M. A., Maah, M. J., & Yusoff, I. (2011). Heavy metals accumulation in plants growing in ex tin mining catchment. *International Journal of Environmental Science and Technology*, *8*, 401–416. https://doi.org/10.1007/BF03326227

Ashraf, M. A., Maah, M. J., & Yusoff, I. (2013). Evaluation of natural phytoremediation process occurring at ex-tin mining catchment. *Chiang Mai Journal of Science*, *40*(2), 198–213.

Briffa, J., Sinagra, E., & Blundell, R. (2020). Heavy metal pollution in the environment and their toxicological effects on humans. *Heliyon*, *6*. https://doi.org/10.1016/j.heliyon.2020.e04691

Cao, L., Jiang, N., Li, B., Deng, J., Duan, Y., Zu, Y., & Li, Z. (2025). Characterization of Cd and As accumulation and subcellular distribution in different varieties of perennial ryegrasses. *BMC Plant Biology*, *25*, 508. https://doi.org/10.1186/s12870-025-06530-w

Chaudhry, H., Nisar, N., Mehmood, S., Iqbal, M., Nazir, A., & Yasir, M. (2020). Indian Mustard *Brassica juncea* efficiency for the accumulation, tolerance and translocation of zinc from metal contaminated soil. *Biocatalysis and Agricultural Biotechnology*, *23*, 101489. https://doi.org/10.1016/j.bcab.2019.101489

Chintani, Y. S., Butarbutar, E. S., Nugroho, A. P., & Sembiring, T. (2021). Uptake and release of chromium and nickel by vetiver grass (*Chrysopogon zizanioides* (L.) Roberty). *SN Applied Sciences*, *3*, 285. https://doi.org/10.1007/s42452-021-04298-w

Chukwu, E. C., & Gulser, C. (2025). Morphological, physiological, and anatomical effects of heavy metals on soil and plant health and possible remediation technologies. *Soil Security*, *18*, 100178. https://doi.org/10.1016/j.soisec.2025.100178

Clemente, R., Walker, D. J., & Bernal, M. P. (2005). Uptake of heavy metals and As by *Brassica juncea* grown in a contaminated soil in Aznalcóllar (Spain): The effect of soil amendments. *Environmental Pollution*, *138*(1), 46–58. https://doi.org/10.1016/j.envpol.2005.02.019

Ehtaiwesh, A. F. (2022). The effect of salinity on nutrient availability and uptake in crop plants. *Journal of Applied Science*, *9*, 55–73. https://doi.org/10.47891/sabujas.v0i0.55-73

Ejaz, U., Khan, S. M., Khalid, N., Ahmad, Z., Jehangir, S., Fatima Rizvi, Z., Lho, L. H., Han, H., & Raposo, A. (2023). Detoxifying the heavy metals: a multipronged study of tolerance strategies against heavy metals toxicity in plants. *Frontiers in Plant Science*, *14*, 1154571. https://doi.org/10.3389/fpls.2023.1154571

Gavrilescu, M. (2022). Enhancing phytoremediation of soils polluted with heavy metals. In *Current Opinion in Biotechnology* (Vol. 74, pp. 21–31). Elsevier Ltd. https://doi.org/10.1016/j.copbio.2021.10.024

Groenendyk, D. G., Ferré, T. P. A., Thorp, K. R., & Rice, A. K. (2015). Hydrologic-process-based soil texture classifications for improved visualization of landscape function. *PLoS ONE*, *10*(6). https://doi.org/10.1371/journal.pone.0131299

He, Y., DeSutter, T., Prunty, L., Hopkins, D., Jia, X., & Wysocki, D. A. (2012). Evaluation of 1:5 soil to water extract electrical conductivity methods. *Geoderma*, *185–186*, 12–17. https://doi.org/10.1016/j.geoderma.2012.03.022

Khairil, M., Siti-Meriam, A., Nur Fatihah, H.N., Nashriyah, M., Razali, M.S. and Noor Amalina, R. (2015). Association of edaphic factors with herbal plants abundance and density in a recreational forest, Terengganu, Peninsular Malaysia. *Malaysian Applied Biology* (2015) 44(2): 33–43.

Khairil, M., W.A. Wan Juliana, M.S. Nizam & W.M. Razi Idris. (2014). Soil properties and variation between three forest types in Tropical Watershed Forest of Chini Lake, Peninsular Malaysia. *Sains Malaysiana* 43(11) (2014): 1635–1643.

Khairil, M., & Burslem, D. F. R. P. (2018). Controls on foliar aluminium accumulation among populations of the tropical shrub *Melastoma malabathricum* L. (Melastomataceae). *Tree Physiology*, *38*, 1–1769. https://doi.org/10.1093/treephys/tpy082

Kohda, Y. H. T., Endo, G., Kitajima, N., Sugawara, K., Chien, M. F., Inoue, C., & Miyauchi, K. (2022). Arsenic uptake by *Pteris vittata* in a subarctic arsenic-contaminated agricultural field in Japan: an 8-year study. *Science of the Total Environment*, *831*, 154830. https://doi.org/10.1016/j.scitotenv.2022.154830

Ma, L. Q., Komar, K. M., Tu, C., Zhang, W., Cai, Y., & Kennelley, E. D. (2001). A fern that hyperaccumulates arsenic. *Nature*, *409*. https://doi.org/10.1038/35078151.

Mahmud, Khairil & David F.R.P. Burslem (2020). Contrasting growth responses to aluminium addition among populations of the aluminium accumulator *Melastoma malabathricum. AoB Plants*, 12(5): 1-10. https://doi.org/10.1093/aobpla/plaa049

Mahmud, Khairil, Hedda Weitz, Ully H. Kritzler & David F. R. P. Burslem (2024). External aluminium supply regulates photosynthesis and carbon partitioning in the Al-accumulating tropical shrub *Melastoma malabathricum*. PLoS ONE 19(3): e0297686.https://doi.org/10.1371/journal.pone.0297686

Martínez, O. G., & Vilte, I. (2012). The structure of petioles in *Pteris* (Pteridaceae). *American Fern Journal*, *102*(1), 1–10. https://doi.org/10.1640/0002-8444-102.1.1

Metali, F., Salim, K. A., & Burslem, D. F. R. P. (2012). Evidence of foliar aluminium accumulation in local, regional and global datasets of wild plants. *New Phytologist*, *193*(3), 637–649. https://doi.org/10.1111/j.1469-8137.2011.03965.x

Murdiono, W.E., Nur Amirah Syafiqah Salman, Halmi, M.I.E, David F.R.P. Burslem, Jean W.H. Yong & Khairil Mahmud. (2025). Effects of leaf ages, altitude and clone types on nutrient elements and antioxidant activity of tea (*Camellia sinensis* L. (O) Kuntze) in tropical conditions. *Applied Food Research* 5 (2025) 10110. https://doi.org/10.1016/j.afres.2025.101110.

Oliveira, L. M. de, Ma, L. Q., Santos, J. A. G., Guilherme, L. R. G., & Lessl, J. T. (2014). Effects of arsenate, chromate, and sulfate on arsenic and chromium uptake and translocation by arsenic hyperaccumulator *Pteris vittata* L. *Environmental Pollution*, *184*, 187–192. https://doi.org/10.1016/j.envpol.2013.08.025

Paul, T. S., Das, B. B., Talekar, Y. P., & Banerjee, S. (2020). Exploration of the role of a lithophytic fern, *Pteris vittata* L. in wound tissue regeneration and remodelling of genes in hyperglycaemic rat model. *Clinical Phytoscience*, *6*(79). https://doi.org/10.1186/s40816-020-00223-7

Rajakaruna, N., Siebert, S. J., & Boyd, R. S. (2019). The edaphic factor in ecology. In *Encyclopedia of Ecology (Second Edition)* (Vol. 3, pp. 361–367). Elsevier. https://doi.org/10.1016/B978-0-12-409548-9.11159-5

Rayment, G. E., & Lyons, D. J. (2010). *Soil Chemical Methods - Australasia*. CSIRO Publishing. https://doi.org/10.1071/9780643101364

Reeves, R. D., Baker, A. J. M., Jaffré, T., Erskine, P. D., Echevarria, G., & van der Ent, A. (2017). A global database for plants that hyperaccumulate metal and metalloid trace elements. In *New Phytologist* (Vol. 218, Issue 2, pp. 407–411). https://doi.org/10.1111/nph.14907

Saberi, N., Halmi, M. I. E., Hamdani, M. S. A., Ramle, N. A., & Mahmud, K. (2024). Metals accumulation of tropical shrub *Melastoma malabathricum* L. (Melastomataceae) populations and their relation to soil edaphic factor. *Malaysian Applied Biology*, *53*(1), 113–125. https://doi.org/10.55230/mabjournal.v53i1.2793

Sahrawat, K. L., Ravi Kumar, G., & Rao, J. K. (2002). Evaluation of triacid and dry ashing procedures for determining potassium, calcium, magnesium, iron, zinc, manganese, and copper in plant materials. *Communications in Soil Science and Plant Analysis*, *33*(1–2), 95–102. https://doi.org/10.1081/CSS-120002380

Singh, M., Malhotra, K., & Singh, C. (2015). Phytochemical evaluation and antioxidant activity of different samples of *Pteris vittata* in Doon Valley, Uttarakhand Region. *Int. J. Pure App. Biosci*, *3*(4), 296–304. www.ijpab.com

Sintorini, M. M., Widyatmoko, H., Sinaga, E., & Aliyah, N. (2021). Effect of pH on metal mobility in the soil. *IOP Conference Series: Earth and Environmental Science*, *737*(1). https://doi.org/10.1088/1755-1315/737/1/012071

Syazwani N. S, Mokhatar S.J., Abas NA, Yong J.W.H. & Khairil M. (2024). Application of *Dendrocalamus asper* (Schult.) Backer (Buluh Betong) with the combination of bamboo biochar and EDTA In phytoremediation. *Journal of Tropical Forest Science* 36(4): 402—415. https://doi.org/10.26525/jtfs2024.36.4.402.

Teh, C. B. S., & Talib, J. (2006). Soil and plant analyses vol. I Soil physics analyses. In *Department of Land Management University Putra Malaysia* (Vol. 1, Issue January).

Tu, C., & Ma, L. Q. (2003). Effects of arsenate and phosphate on their accumulation by an arsenic-hyperaccumulator *Pteris vittata* L. *Plant and Soil*, *249*(2), 373–382. https://doi.org/10.1023/A:1022837217092

Xiao, X., Chen, T., An, Z., Lei, M., Huang, Z., Liao, X., & Liu, Y. (2008). Potential of *Pteris vittata* L. for phytoremediation of sites co-contaminated with cadmium and arsenic: The tolerance and accumulation. *Journal of Environmental Sciences*, *20*(1), 62–67. https://doi.org/10.1016/S1001-0742(08)60009-1

Yu, H., Li, S., & Wang, A. (2020). Accumulation of heavy metals and As in the fern *Blechnum orientale* L. from Guangdong Province, Southern China. *Water, Air, and Soil Pollution*. https://doi.org/10.1007/s11270-020-04645-4

Zarcinas, B. A., Fauziah Ishak, C., Mclaughlin, M. J., & Cozens, G. (2004). Heavy metals in soils and crops in southeast Asia. 1. Peninsular Malaysia. In *Environmental Geochemistry and Health* (Vol. 26).

Zhang, W., Cai, Y., Tu, C., & Ma, L. Q. (2002). Arsenic speciation and distribution in an arsenic hyperaccumulating plant. *The Science of the Total Environment*, *300*, 167–177.

Zineb, E. M., Rabea, Z., Ahmed, D., Sahar, B., Ibtissame, L., Loubna, B., Najiba, B., & Rachid, M. (2023). Comparison between Walkley-Black and Loss on Ignition methods for organic matter estimation in different Moroccan Soils. *Ecological Engineering and Environmental Technology*, *24*(4), 253–259. https://doi.org/10.12912/27197050/163121