Eurasian J. For. Res. 20: 11-20 , 2017

Concentration of Some Trace Elements in Two Wild Edible Ferns, *Diplazium esculentum* and *Stenochlaena palutris*, Inhabiting Tropical Peatlands under Different Environments in Central Kalimantan

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Abstract

Young leaves of two wild ferns (*Diplazium esculentum* and *Stenochlaena palutris*) are uniquely eaten among local peoples in Kalimantan Island. These edible ferns are regarded as important sources of Fe and other trace elements essential for human body. In order to investigate the effect of soil environments on the metal content, we analyzed eight elements (Al, Fe, Cr, Cu, Mn, Zn, Cs, and Pb) in the edible ferns collected from five different sites (riverside of Kahayan River near Bukit Rawi, farming area in Tangkiling, natural forest near Kasongan, and two peat soils at campus of The University of Palangkaraya and residential area in Palangkaraya city) in Central Kalimantan with distinguishable soil conditions. At the five sampling locations, we also collected an aluminum accumulator bush tree (*Melastoma malabathricum*) as a reference plant. The underground parts of *S. palutris* and *D. esculentum* accumulated higher concentration of Al and Fe than their leaf parts, whereas *M. malabathricum* was rich in Al and Mn in the leaves rather than the roots. Although Fe contents in the edible parts of *D. esculentum* (3.1–3.3 μg/g-dry weight of young leaves) and *S. palutris* (1.0–2.1 μg/g dw leaves) from the samples collected at the riverside and the farming area were not so high, Al contents in their edible parts (3.9–6.3 and 7.8–7.9 μg/g-dry weight, respectively) were not excessive. Other trace elements, including Mn, was not the levels to be concerned. Thus, utilizing young leaves and shoots of the ferns as wild vegetable seemed to cover chronical deficiency of trace elements necessary for human nutrition, without any excessive intake of Al and other toxic metals, unless collected at urban area. We further found relatively high Cs-absorbable cropping plants in this study.

Key words: edible fern, tropical peatland, wild vegetable, heavy metal contents, iron and mineral supplier

Introduction

Central Kalimantan is one of the regions in Indonesia with a high diversity of vegetation, and local peoples utilize some young wild ferns as edible natural vegetables. Irawan *et al.* (2006) reported that locally edible fern kalakai (*Stenochlaena palustris* (Burm) Bedd) contained 10-50 times higher Fe than other common leafy vegetables, which suggested high potentials of the peatland-adaptable edible ferns to accumulate heavy metals or essential trace elements. Because tropical peat soil is poor in minerals (Andriesse 1988), local peoples living in Central Kalimantan would have matured unique fern-eating culture to overcome such nutritional disadvantage in the acidic Histosol-based closed ecosystem established on tropical peat swamp forest. Therefore, we investigated several metal contents in the edible part of the ferns grown at several sites in Central Kalimantan to compare with some local vegetables cultivated there and other vegetables cultivated in Bogor, Java, Indonesia. The wild edible ferns locally consumed in Central Kalimantan are kalakai (*Stenochlaena palustris* (Burm) Bedd) and bajei (*Diplazium esculentum* (Retz) S.W), and other wild edible plants are pucuk rotan (*Calamus* sp.), lampinak (*Cnesmone javanica*), daun taya (*Nauclea* sp.), and so on. Most of these edible plants are not cultivated, however, easy to find throughout any local habitat and consumed by local peoples in Dayak communities in Central Kalimantan like green vegetable or herbal medicine against anemia, fever, and cutaneous disorders (Irawan *et al.* 2006).

As many ferns are known as heavy metal accumulators (Pongthornpruek *et al.* 2008; Reimann *et al.* 2007), fern plants sometimes accumulate metals in their edible parts, too. Hence, health effects of the fern-eating food culture depend on their mineral

(Received; April. 5, 2017: Accepted; July. 3, 2017)
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constituents mainly due to their nutritional or toxicological characteristics (Yang *et al.* 2011). Although some of the metals such as Zn, Mn, Ni, and Cu act as micro-nutrients at lower concentration, they are rather toxic at higher concentration. Previous study reported that morphological abnormalities, growth repression, or mutagenic effects in human were often caused by harmful concentration of heavy metals (Li *et al.* 2010). Consequently, it would be concerned about increasing risks of heavy metal accumulation in toxic level in such edible young leaves due to human activity.

As an ethnobotanical study, nutrient potency of some wild, edible plants, including those two edible ferns and other local edible plants and local vegetables in Central Kalimantan, was investigated. The edible ferns (*S. palustris* and *D. esculentum*) in Central Kalimantan had similar levels of Fe (23 and 26 µg/g-dry weight) in previous study done by Dwinawati *et al.* (2004), whereas Irawan *et al.* (2006) showed that not only Fe but also Cu and Zn in the aforementioned wild edible plants in Central Kalimantan were higher than those reported by Dwinawati *et al.* (2004). However, both researches never focused on condition of the soils where the samples were growing.

Thursina *et al.* (2010) have analyzed the exogenic factors for mineral contents of *S. palustris*, such as land conditions of its habitat, and cooking method toward minerals of the edible fern leaves. Some other reports also showed that concentration of metals in edible part of vegetables was highly linked to concentration of metals in soil as an exogenic factor. Fialkowski *et al.* (2012) revealed that chemical and biological properties of metal accumulators are highly related to mobility and bioavailability of metal cations in soil. In earlier studies, samples of vegetables which were cultivated in different farming areas had been analyzed to quantify concentration of the heavy metals and essential micro-nutrition in different parts of vegetables along with the quantitative analysis of mineral contents (Thursina *et al.* 2010), so it was still uncertain whether those high metal contents of some wild vegetables are due to conditions of the soils they were growing.

In this study, we analyzed contents of some important metals in two edible, acidic peat soil-adapting ferns (*S. palutris* and *D. esculentum*), and further discussed merits in eating the wild edible ferns for mineral uptake or risks due to heavy metal pollution (Hodson, 2012). For the same purpose, contents of some important metals in several local vegetables in Central Kalimantan were compared to several leafy green vegetables cultivated in Bogor, West Java, to discuss further on risks of excessive heavy metal intake via wild vegetables in the local area. Also, we searched for possible Cs accumulators showing relatively high Cs contents among the local vegetables grown in tropical peat soil, because tropical peat soil is generally poor in Cs^+ and K^+ compared to mineral soils. Taken together, we wish to discuss the value of such local vegetables in the aspect of their potentials for selective metal uptake and accumulation.

Materials and Methods

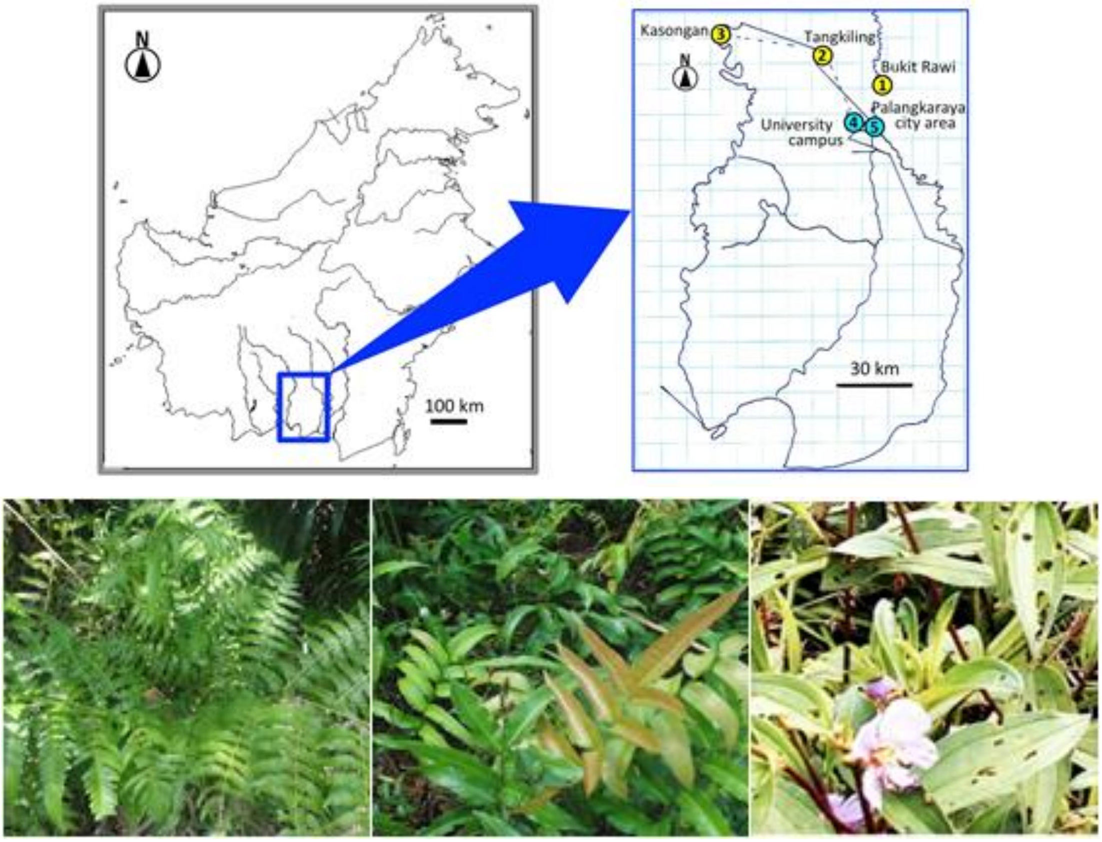
Sampling location and materials

Sampling sites of the edible ferns are located at riverside of Kahayan River (site no. 1, Bukit Rawi, 2.096S, 113.940E), farming area in a village (no. 2, Tangkiling, 2.139S, 113.825E), natural forest area near Sebangau River (no. 3, Kasongan, 1.908S, 113.375E), campus at The University of Plangkaraya (no. 4, University campus, 2.219S, 113.893E), urban residential area (no. 5, Palangkaraya City, 2.199S, 113.903E) in Central Kalimantan Province (Fig. 1). The climate there is generally wet for eight months (October to May) for the rainy season. Samples used as the focused plants were the wild edible ferns (*Stenochlaena palutris* and *Diplazium esculentum*) and a non-edible, aluminum-accumulator *Melastoma malabathricum* as a reference plant which is low bush tree and grows everywhere throughout the open acidic lands in Central Kalimantan. The samples (roots and leaves) were collected from the five sites (Table 1).

Table 1. Species, habitat, and edible part of analyzed plants.

Plant	Site no	Habitat	Samples
Stenoclaena palutris	1	Riverside along Kahayan River near Bukit Rawi village	young leaf/root
	2	Farming area at Tangkiling village	young leaf/root
	3	Natural forest near Kasongan village	young leaf/root
	4	Campus area at The Uversity of Palangkaraya	young leaf/root
	5	Residential area in Palangkaraya city	young leaf/root
Diplazium esculentuma	1	Riverside along Kahayan River near Bukit Rawi village	young leaf/root
	2	Farm site in Tangkiling village	young leaf/root
Melastoma malabathricum	1	Riverside along Kahayan River near Bukit Rawi village	mature leaf/root
	2	Farm site at Tangkiling village	mature leaf/root
	3	Natural forest near Kasongan village	mature leaf/root
	4	Campus area at The Uversity of Palangkaraya	mature leaf/root
	5	Residential area in Palangkaraya city	mature leaf/root

All the sampling area are basically peatland. [a] Note that *D. esculentum* preferring relatively moist, non-shaded open area was not found in the sites 3, 4 and 5.



Diplazium esculentum ***Stenochlaena palutris*** ***Melastoma malabathricum***

Fig. 1. Map of study sites and plants collected
Top panels: (left) a map of Kalimantan Island; (right) a zoomed map for sampling sites in Central Kalimantan. Bottom panels: plants collected. Young shoots and leaves of two ferns (left and center panels) are edible. Mature fruit of *M. malabathricum* (right panel) is edible but leaves are not edible.

The edible ferns *S. palutris* and *D. esculentum* are consumed by people in local community in Central Kalimantan. As the local people usually utilize young leaves of *S. palutris* and *D. esculentum* as daily vegetable, only edible young leaves were collected. Those edible ferns are growing as natural vegetation throughout open-peatland area. *D. esculentum* is higrofit plant which can be found on the bank of streams, rivers and moist area (Archana *et al.* 2013). Therefore, these plants have been collected at the riverside of Kahayan River and at farming area at Tangkiling in this study. Compared to *D. esculentum*, *S. palutris* had more adaptability to survive throughout critical lands, such as burned-over land. In this study, *S. palutris* has therefore been collected from all the sampling sites, including campus of Palangkaraya University, residential area in Palangkaraya City, and forest area, as well as the riverside and the farming area.

M. malabathricum, a reference plant, was also collected at all of the sampling sites. This plant is also known as an aluminum-accumulator in tropical acidic soils which can accumulates Al at more than 10 mg/g-dry weight of the leaf tissues (Watanabe *et al.* 2008). In addition, 15 leafy local vegetables were purchased from local markets from Palangkaraya, and 14 vegetables were collected from a traditional market in Bogor, West Java Province, for comparisons.

Metal analysis

For the metal analysis, the following reagents were used: ultrapure water (Milli-Q water) (Q-POD Millipore, Billerica, MA, USA), ultra-pure nitric acid (grade for analysis of poisonous metal, Wako, Osaka, Japan), 30% hydrogen peroxide for Atomic Absorption Spectrochemical Analysis (Wako), and a mixed standard solution of Fe, Cr, Cu, Cd, Mn, Pb, Zn and Na with high purity, Standard solutions of metals (Atomic absorption spectrophotometer grade, Kanto Chemical Co, Tokyo, Japan). An Al 1000, an aluminum standard solution (1000 mg L^{-1} Al^{3+} in 0.4-0.6 M HNO_3) purchased from Wako (Osaka, Japan) was 100 fold-diluted for use, and Cs concentration was calculated using peak intensity of Na cation. Metal contents of vegetables and soils were determined by ICP-MS (Inductively coupled plasma-mass spectrometry) (Elan DRC; Perkin Elmer, Waltham, MA, USA) and MP-AES (microwave plasma-atomic emission spectrometry) (4100 MP-AES, Afilent Technologies, Santa Clara, CA, USA).

Sample preparation

Fresh leaves and roots of *S. palutris* and *D. esculentum* were collected from the five sampling locations, each part of vegetables was cleaned with MilliQ water, recorded precise fresh weight, and then oven-dried at 60−70°C for 32 h. The total moisture content of sample of fresh roots and leaves from each plant was determined by the reduction of dry weight from its fresh weight, and then the dried samples were crushed and pulverized with a stainless steel crusher to be fine powders. Each sample of the plant materials was stocked in a Ziplock® plastic bag, and kept in a store room at room temperature until use. Fifteen leafy local vegetables from Palangkaraya and 14 leafy vegetables from Bogor were also processed by the same manner as did for the edible ferns.

Soil near the roots of respective plants sampled were randomly collected with a stainless steel auger at the same sites, generally at depth of 30 cm. The soil samples were air dried and grounded to obtain fine powders (ø < 2 mm). In the fumehood, 0.50 g of dry soil was weighed and placed in a vial, then added 10.0 mL of HNO_3. The vial was closed tightly and placed in microwave system. The temperature of microwave was maintained at 185°C for 10 min. After completion of the digestion, the sample cooled down was transferred to a 100-mL volumetric flask and then settled overnight. The supernatant was decanted and stored into a polyethylene bottle until use for the further analysis (USPEA 2007).

Sample degradation with nitric acid and hydrogen peroxide

Concentration of Fe, Cr, Al, Mn, Zn, Cu, Pb, and Cs was determined after wet destruction of dried plant tissue. Some wild, edible plants may accumulate the absorbed metals by taking from the soils, as well as from the air (Zurera *et al.* 1989), and some metals showing damaging effects on human beings and animals such as Cr, Pb and Al do not have proper mechanism to eliminate the metals on chronic level intakes.

Exactly 100 mg dried powder of a plant sample was placed in a digestion tube (20-mL glass vial), and digested in 5 mL ultra-pure nitric acid (grade for analysis of poisonous metal, Wako, Osaka, Japan). The sample was heated to 95°C on a heating block (Corning Inc., Corning, NY, USA) filled with celite beads for approximately 1 h. After cooling, 1 mL of 33% hydrogen peroxide (grade for atomic absorption spectroscopic analysis, Wako) was added, and the samples heated to 140°C until solids were completely dissolved with nitric acid. This procedure was repeated until a dark brown color become completely clear and colorless or pale yellow (Şenilă *et al.* 2011). The digested solution was cooled to room temperature, moved into a 10 mL volumetric flask, added 3% nitric acid to 10 mL and filtered through an aseptic membrane filter (Millex®-GV sterile, 0.22 µm, PVDF, Merck Millipore Ltd., Darmstadt, Germany), put into a tube, and then kept in a room temperature until use.

Statistical analysis

Mean and standard deviation of the metal contents in plant materials were calculated using a statistical package program of Microsoft Office Excel 2007.

Results

Metal in soil

Soil-to-plant transport of minerals is one of the key for uptake of trace elements for human via foodchain. Among the soils from 5 sampling locations, the highest concentration of Al was found in the site of the University campus and the residential area of Palangkaraya City (1.2 and 1.3 mg/g-dry weight soil respectively), both of which are acidic mineral soils in the range from pH 3.5 to 4.0 (Table 2). In such acidic, Al-rich soil, Al is often present as soluble form, and the highest concentration of Al in the leaves and the roots of *M. malabathricum* was detected in those specimens collected from the residential area of Palangkaraya City. Based on FAO Land and Water Development Division (1988), type of soil in Palangkaraya is reclaimed tropical peatlands which eventually contained high levels of Al, Fe, and Mn. Conversely, the highest concentration of Fe was the soil from the riverside of Kahayan River (99.2 µg/g-dry weight).

Metal contents of *D. esculentum* and *S. palutris* from Palangkaraya

Present study showed that Al, Fe, and Mn are the top three major metals, while Pb, Cr, and Cs were less than 0.1 µg/g-dry weight (d.w.) and Zn and Cu were less than 2.2 µg/g d.w., mostly at the levels of 1.0 and 0.2 µg/g d.w. respectively (data not shown). Metal contents in the roots of *S. palutris*, *D. esculentum*, and *M. malabathricum* were generally higher than the leaves, except for Zn and Cs. Only in the leaves of *M. malabathricum*, Mn content was remarkably high (Table 3). The highest metal in the edible parts of *S. palutris* and *D. esculentum* in all the sampling locations was Al. However, *S. palutris* that showed the highest Al accumulation among the samples from the five sampling sites was those collected at the riverside in Bukit Rawi where the land was highly affected by mineral sediments.

Our study also showed that *S. palutris* and *D. esculentum* have significantly higher Fe concentration than the Al-accumulator *M. malabathricum* in any locations. The Al concentration in the leaves of *M. malabathricum* was 24.9–264.2 µg/g-dry weight in all the sampling locations. In addition, it was also obvious that *M. malabathricum* was a Mn-accumulator, particularly in the leaves. Fe contents in soil at the sites 1 (riverside), 2 (farming area), and 3 (natural forest) were much higher than Mn, with Mn/Fe ratios (mg/mg) of 0.21, 0.42, and 0.22 in the soils respectively (Table 2). Nevertheless, Mn contents in the leaves of *M. malabathricum* were much higher than Fe (Mn/Fe ratios of 45.6−176.7), showing a selective absorption and accumulation of Mn by this plant (Table 3).

Table 2. Metal contents of soils from five sampling location in Palangkaraya

Site no.	Location	Metals (µg/g-dry weight, n=3)							
		Fe	Al	Mn	Cu	Zn	Pb	Cr	Cs
1	Riverside (Bukit Rawi)	99.2	480	21.0	5.4	8.9	5.2	0.28	NA
2	Farming area (Tangkiling)	28.3	76	11.9	0.1	3.7	0.7	0.01	NA
3	Natural forest (Kasongan)	95.8	200	20.8	4.8	5.0	2.9	0.08	NA
4	University campus (UNPAR)	28.7	1218	2.4	0.2	4.7	0.4	0.07	NA
5	Residental area (Palangkaraya)	18.7	1300	51.3	0.1	20.9	0.6	0.01	NA

Soil samples (total 1 kg of raw bulk soil) were mixed well in a plastic bag, and the resulting soil as a 1 g portion of dry one was used for the analysis. NA, not analyzed. Caption next to the location is land name.

Table 3. Concentration of Al, Fe, and Mn in plant tissues of wild edible ferns and wild non-edible plants from five sampling locations in Palangkaraya

Plant	Location	Part	Contents of three major metals (µg/g-dry weight)		
			Al	Fe	Mn
I. Edible fern					
Diplazium esculentum	Bukit Rawi	root	288.9 ± 1.2	162.5 ± 1.9	14.1 ± 0.0
(Bajei)	(riverside)	leaf	6.3 ± 0.2	3.3 ± 0.2	1.5 ± 0.0
	Tangkiling	root	158.4 ± 0.4	438.5 ± 0.9	8.2 ± 0.2
	(farmland)	leaf	3.9 ± 0.1	3.1 ± 0.1	2.0 ± 0.0
Stenochlaena palutris	Bukit Rawi	root	678.3 ± 2.0	207.2 ± 0.8	1.5 ± 0.0
(Kalakai)	(riverside)	leaf	7.9 ± 0.1	1.2 ± 0.0	2.6 ± 0.0
	Tangkiling	root	48.7 ± 0.4	12.1 ± 0.2	1.8 ± 0.0
	(farmland)	leaf	6.8 ± 0.1	1.0 ± 0.0	2.1 ± 0.0
	Kasongan	root	146.3 ± 0.7	98.0 ± 0.7	2.1 ± 0.0
	(natural forest)	leaf	7.8 ± 0.1	2.1 ± 0.1	2.8 ± 0.0
	University campus	root	86.6 ± 0.6	23.9 ± 0.1	1.1 ± 0.0
	(campus area)	leaf	5.6 ± 0.1	2.0 ± 0.0	1.8 ± 0.0
	Palangkaraya City	root	90.4 ± 0.6	8.7 ± 0.1	2.6 ± 0.0
	(residential area)	leaf	6.0 ± 0.1	0.9 ± 0.0	2.7 ± 0.0
II. Non-edible plant					
Melastoma malabathricum	Bukit Rawi	root	68.3 ± 0.4	4.5 ± 0.0	7.4 ± 0.0
(Senduduk)	(riverside)	leaf	24.9 ± 0.4	0.5 ± 0.0	22.8 ± 0.2
	Tangkiling	root	320.2 ± 0.4	6.0 ± 0.3	2.0 ± 0.0
	(farmland)	leaf	117.2 ± 0.8	0.4 ± 0.1	53.0 ± 0.2
	Kasongan	root	26.0 ± 0.3	0.3 ± 0.0	7.4 ± 0.4
	(natural forest)	leaf	162.4 ± 0.1	0.3 ± 0.1	21.1 ± 0.2
	University campus	root	431.8 ± 0.9	2.6 ± 0.1	1.6 ± 0.0
	(campus area)	leaf	264.2 ± 1.9	0.8 ± 0.0	25.2 ± 0.2
	Palangkaraya City	root	478.2 ± 1.2	1.9 ± 0.1	5.1 ± 0.1
	(residential area)	leaf	262.9 ± 1.6	1.1 ± 0.1	10.8 ± 0.1

n=3, mean ± standard deviation.

In the riverside of Kahayan River in Bukit Rawi and the farming area in Tangkiling, *S. palutris*, *D. esculentum*, and *M. malabathricum* had different properties in metal accumulation. In *S. palutris*, the second highest metal accumulated was Fe (207.2 µ/g-dry weight root from the riverside in Bukit Rawi village), but only 2.6 µ/g-dry weight of the edible part. In the same study, *D. esculentum* showed similar contents of Fe in the leaves and roots. Hence, Fe/Al ratios of *S. palutris*, *D. esculentum*, and *M. malabathricum* collected at the sampling sites, except for two urban areas, were plotted in Fig. 2, showing that both *S. palutris* and *D. esculentum* less accumulated Al in their edible parts. In their roots, *S. palutris* and *D. esculentum* conversely showed active accumulation of Fe and Al. Higher accumulation of Al in the mature leaves of *M. malabathricum* was in a good accordance with aforementioned statement that *M. malabathricum* is a remarkable Al-accumulator, positively absorbs Al even from Al-poor peat soils.

Comparison of metals contents in leafy vegetables from peatlands and volcanic soils

Based on previous study (Irawan *et al.* 2006), it was suggested that soil condition in cultivated or growing place highly affected mineral and heavy metal contents of the edible plants. Indeed, concentration of Fe and Al in *S. palutris* and *D. esculentum* in Central Kalimantan depends on naturally inhabiting or cultivated soil conditions. Therefore, patterns of metal content in some local green vegetables in Palangkaraya market were compared with some more vegetables in West Java grown on volcanic mineral soils (Tables 4 and 5). In this study, additional 14 leafy vegetables from Bogor and 15 wild or locally cultivated edible plants from Palangkaraya, including *S. palutris* and *D. esculentum*, were analyzed for comparison of the eight metal cations.

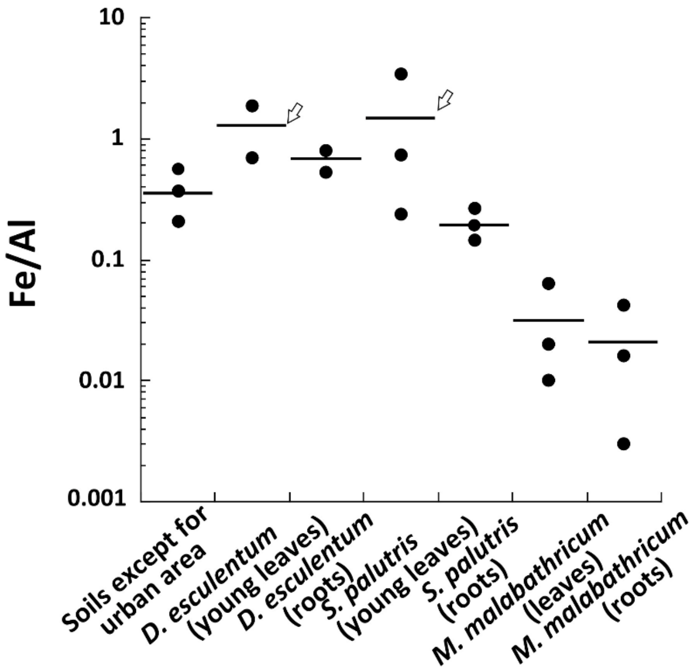


Fig. 2. Concentration ratio of Fe/Al in two edible ferns from river side and farmland
Al and Fe correlation among two edible ferns *S. palutris* and *D. esculentum* are shown by Fe/Al ratio. *M. malabathricum*, an aluminum-accumulator plant all collected at the same sampling sites, was shown for comparison with the ferns. Bar is a value of Fe/Al ratio averaged (n= 2–3). Note remarkably selective accumulation of Fe in edible part (young leaves) of the ferns.

Table 4. Metal contents in local vegetables from Palangkaraya

No	Name of vegetable	Metals (µg/g-dry weight of leaves)							
		Cr	Fe	Cu	Mn	Zn	Pb	Al	Cs
1	*Stenochlaena palutris*	0.02 ± 0.01	8.36 ± 4.8	2.02 ± 0.36	11.0 ± 6.3	7.22 ± 0.91	1.55 ± 0.33	10.5 ± 6.4	2.15 ± 1.85
2	*Diplazium esculentum*	0.05 ± 0.01	15.7 ± 5.8	3.99 ± 0.31	7.03 ± 6.46	7.53 ± 0.98	2.46 ± 0.34	18.3 ± 8.5	ND
3	*Cucumis sativus*	0.11 ± 0.02	159.0 ±16.4	1.02 ± 0.04	13.2 ± 0.16	3.90 ± 0.09	2.63 ± 0.14	255.6 ± 4.4	ND
4	*Cucurbita moschata*	1.07 ± 0.40	12.7 ± 3.5	1.46 ± 0.06	10.6 ± 0.10	6.57 ± 1.00	0.91 ± 0.04	20.4 ± 4.7	ND
5	*Momordica charantia*	0.99 ± 1.17	11.8 ± 5.4	1.05 ± 0.47	14.4 ± 6.7	5.84 ± 1.38	1.08 ± 0.29	15.6 ± 8.0	ND
6	*Nauclea* sp.	0.04 ± 0.03	7.10 ± 4.15	0.83 ± 0.12	4.74 ± 0.13	3.00 ± 1.10	1.97 ± 0.79	48.1 ± 3.8	ND
7	*Manihot esculenta*	1.27 ± 0.47	5.45 ± 0.29	0.85 ± 0.03	27.4 ± 1.2	5.83 ± 0.04	1.11 ± 0.03	3.68 ± 1.10	ND
8	*Cnesmone javanica*	0.03 ± 0.01	8.96 ± 2.54	0.70 ± 0.06	27.5 ± 1.1	17.2 ± 0.32	0.96 ± 0.12	16.4 ± 3.3	ND
9	*Vernonia cinerea*	0.05 ± 0.01	26.0 ± 5.0	0.79 ± 0.05	11.7 ± 0.7	8.05 ± 0.07	1.30 ± 0.03	37.9 ± 4.0	ND
10	*Passiflora feotida*	0.59 ± 0.97	5.74 ± 0.28	0.84 ± 0.06	17.1 ± 0.8	7.72 ± 0.55	1.38 ± 0.08	10.0 ± 3.7	ND
11	*Limmocharis flava*	0.09 ± 0.14	4.75 ± 0.32	0.80 ± 0.06	5.26 ± 0.11	9.00 ± 0.55	0.86 ± 0.05	4.97 ± 1.52	4.71 ± 12.15
12	*Carica papaya*	0.12 ± 0.13	6.43 ± 0.80	0.82 ± 0.08	6.60 ± 0.34	3.62 ± 0.10	1.36 ± 0.10	6.63 ± 0.54	13.6 ± 9.2
13	*Sauropus androgynus*	4.88 ± 4.51	5.40 ± 0.15	0.57 ± 0.01	41.7 ± 2.1	8.37 ± 0.28	1.58 ± 0.04	8.47 ± 2.12	ND
14	*Neptunia oleraceae*	0.05 ± 0.01	13.0 ± 1.7	0.55 ± 0.07	6.82 ± 0.52	5.74 ± 0.66	0.71 ± 0.09	13.2 ± 3.4	2.84 ± 8.54
15	*Lactuca indica*	0.02 ± 0.01	3.09 ± 0.20	0.80 ± 0.02	44.0 ± 1.9	2.92 ± 0.13	0.62 ± 0.51	8.82 ± 0.30	19.6 ± 9.7

n=3, mean ± standard deviation.

Present study revealed the correlation between Al and Fe contents in leafy vegetables from both Palangkaraya and Bogor markets (Fig. 3). These correlation curves exactly show that Al and Fe have similar characteristics and behaviors, both of which are soluble in acidic conditions and have active transporting system on the roots (Trueman *et al.* 2013). All the local vegetables from a local market in Palangkaraya had a similar pattern of metal contents with the wild edible plants *S. palutris* and *D. esculentum* collected from natural vegetative area (Table 3). The highest metal among the samples is Al. Fe was also rich in some local vegetables, such as leaves of *Cucumis sativus* and *Vernoria cinerea*, from the Palangkaraya market (Table 4). In addition, Mn contents were relatively high in all the vegetables locally cultivated, particularly *Sauropus androgynous* and *Lactuca indica*.

Micro-elemental analysis in this study also revealed high potentials of some peat soil-adaptable local vegetables as Cs-accumulators. Indeed, some of the peat-adaptable local vegetables are a potent candidate for bioremediating plants to remove Cs in humus-rich soils. We analyzed Cs contents in the local vegetables, and found that two leafy vegetables from Palangkaraya (*Lactuca indica* and *Carica papaya*) contained significant amounts of Cs, despite of low availability of Cs in acidic peat soils.

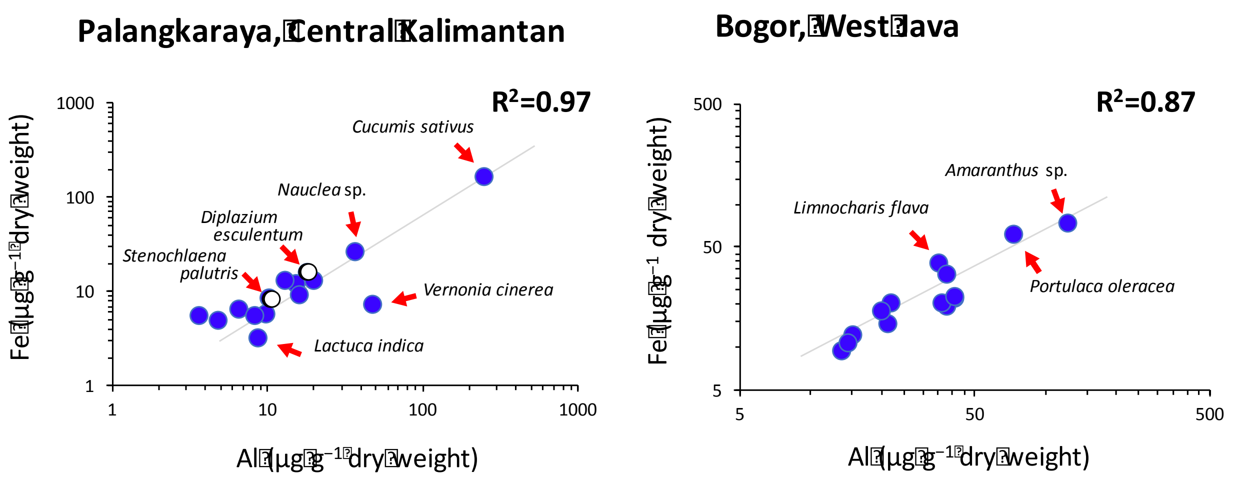


Fig. 3. Correlation between Fe and Al contents in local vegetable collected from local markets at Bogor and Palangkaraya
Both groups of the local vegetables were collected from local markets at Palangkaraya (Central Kalimantan) and Bogor (West Java), respectively. The land used for agriculture in Central Kalimantan is mainly tropical peat soils, while farmland in West Java is basically mineral oxisols. Arrows are for some unique vegetables (selectively Fe-rich, selectively Al-rich, or both). Note that *Cucumis sativus* (cucumber) is outstandingly rich in both Fe and Al as μg/g dry weight of the plant materials, but its water content is also outstandingly high. Plots of the edible ferns shown by black filled circles were also shown by arrows.

Table 5. Metal contents in leafy local vegetables from Bogor

No	Name of vegetable	Metals (μg/g-dry weight of edible part)							
		Cr	Fe	Cu	Mn	Zn	Pb	Al	Cs
1	*Ipomea aquatica*	0.06 ± 0.01	21.9 ± 4.9	1.25 ± 0.99	14.5 ± 3.8	2.93 ± 0.17	1.10 ± 0.17	41.0 ± 0.9	ND
2	*Oenanthe javanica*	0.03 ± 0.00	14.4 ± 4.8	1.27 ± 0.98	10.8 ± 0.6	3.35 ± 1.07	0.88 ± 0.38	21.3 ± 3.6	ND
3	*Pilea melastomoides*	0.16 ± 0.12	9.20 ± 1.54	0.33 ± 0.04	5.49 ± 0.95	1.98 ± 0.64	ND	13.7 ± 1.2	ND
4	*Portulaca oleracea*	0.04 ± 0.02	61.0 ± 23.4	1.35 ± 0.07	41.3 ± 12.4	4.85 ± 1.50	1.04 ± 0.79	73.1 ± 14.8	ND
5	*Talinum triangulare*	0.07 ± 0.08	19.1 ± 0.1	1.25 ± 0.24	7.11 ± 3.74	4.88 ± 1.11	ND	38.1 ± 3.6	ND
6	*Pluchea indica*	0.02 ± 0.01	20.2 ± 0.4	1.35 ± 0.04	8.47 ± 0.01	2.01 ± 0.27	ND	22.2 ± 5.6	ND
7	*Cosmos caudatus*	0.03 ± 0.01	17.6 ± 0.6	0.99 ± 0.16	6.57 ± 0.37	2.06 ± 0.32	0.36 ± 0.31	20.1 ± 3.8	9.43 ± 16.37
8	*Nothopanax scutellarium*	0.14 ± 0.14	20.3 ± 2.4	0.74 ± 0.19	12.3 ± 5.9	4.43 ± 0.79	ND	36.4 ± 1.9	ND
9	*Polyscias pinnata*	0.03 ± 0.02	12.0 ± 2.9	0.76 ± 0.09	33.0 ± 0.3	5.07 ± 1.86	0.76 ± 0.41	15.3 ± 6.5	ND
10	*Limnocharis flava*	0.04 ± 0.01	38.2 ± 1.5	0.60 ± 0.09	36.2 ± 0.6	2.84 ± 0.45	0.60 ± 0.02	35.4 ± 6.2	ND
11	*Amaranthus* sp.	0.04 ± 0.00	72.2 ± 4.4	0.86 ± 0.33	56.0 ± 10.0	3.21 ± 1.20	1.92 ± 0.06	124.2 ± 5.0	ND
12	*Sauropus androgynus*	1.45 ± 1.27	10.6 ± 4.3	0.62 ± 0.16	24.4 ± 4.5	5.01 ± 2.10	0.80 ± 0.24	14.5 ± 3.5	ND
13	*Anredera cordifolia*	0.04 ± 0.01	22.2 ± 1.4	1.44 ± 0.22	6.21 ± 0.65	5.99 ± 0.76	1.20 ± 0.50	41.2 ± 6.6	ND
14	*Ocimum americanum*	0.03 ± 0.01	31.5 ± 3.2	1.33 ± 0.51	7.60 ± 0.01	5.06 ± 0.88	1.21 ± 0.67	38.3 ± 1.2	ND

n=3, mean ± standard deviation.

Discussion

Metal contents of *D. esculentum*, *S. palutris*, and soils from Palangkaraya

Each soil type had different concentration of those metals, depending on four factors of soil environment as follows: 1) metal cation chelators produced by plants and released into rhizosphere to solubilize mineral elements in the soils, 2) cation transporters of plants to assist selective absorption of trace elements from the roots, 3) metal cation-binding protein to assist selective transport of the elements from roots to shoots, and 4) immobilization and accumulation of toxic metals in cell wall or vacuoles (Robinson *et al.* 2005; Peng and Gong, 2014). These differences might result into the selective uptake and transport of metal cations by the root and vascular systems. It has been reported that along to the path of soil to the leaf, there are several control points and processes that allow plants to accumulate or exclude elements in their leaves (Adler *et al.* 2012).

Almost all of the soil sampling sites undertook the reclamation by human, leading to the disappearance of the overlying peat and often exposure to the mineral sediments. This peat degradation has often resulted in the development of acid sulfate soil (Haraguchi 2007). Conversely, humus allowed accelerated leaching of Fe^{3+} from the topsoils by forming humic acid-Fe complex at pH 4.0 in freshwater (Fang *et al.* 2015). As Fe is an essential but deficient trace element in tropical peatland ecosystem, the ferns would have a high uptake ability of Fe^{3+} together with a similar trivalent cation Al^{3+}. Then, acidic leachates dissolve Al, Fe and other metals from soil and sediment, potentially impacting on the environment (EPA Victoria 2009). Highly concentrated Fe in the riverside soil is probably provided by flooded river water as mineral-rich sediments. In addition, two toxic metals, Pb and Cr, with relatively high contents in soil at the riverside were likely provided from the sediments from Kahayan River. Thus, soil conditions of the sampling area clearly affect the metal contents in the edible part of the ferns.

Hyper-accumulation of Al in *S. palutris* is accordance with another study conducted by Pongthornpruek *et al*. (2008), in which accumulation of heavy metals (Pb, Ni, and Mn) in several tropical fern species has been reported, but they measured neither Al nor Fe. Concentration of Al in *S. palutris* in our study was higher than that reported by Thursina *et al*. (2010). Such hyper-accumulation of Al in *S. palutris* in our study, particularly obvious in the samples collected in urban area, is probably due to dissolution of Al within the medium-strongly acidic soil as described by Colombo *et al*. (2014) (Table 2). Local people never eat these ferns grown in urban area, as if they know that the ferns are possibly polluted with toxic metals. Therefore, these edible ferns grown in rural bushes and preferably consumed by the local people are probably good sources of Fe as noted by Irawan *et al*. (2006).

Nutritional characteristics of leafy vegetables from peatlands and volcanic soils

Each plant has different ability to uptake metals (Islam *et al.* 2007), while conditions of the soils, which the local vegetables were highly adapted to, are also important factor in metal accumulation. Generally, Histosol (woody peat soils) in Central Kalimantan is rich in organic matters while poor in minerals, including Fe, Cu, and Zn. Hence, the edible ferns would be regarded as relatively a safe and good source of Fe for the people in the peatland region. In contrast, soil type of Bogor area are generally immature volcanic ash soil and red soil, both of which are rich in Fe and Al. Probably due to mineral soils, local vegetables from Bogor richly accumulated Al, Fe, Mn, and Zn.

As Cs and K show similar characteristics and chemical behaviors, Cs^+ is erroneously recognized by K^+ transporter of plants (Zhu and Smolders 2000, Kondo *et al.* 2015, Neverisky and Abbott 2016). Plants with a high ability to absorb K^+ from soils poor in mineral elements possess active K^+-H^+ symporter. Hence, the woody peat soil-adapted vegetables have probably developed K^+-H^+ symporter. Cs transport to the root cells would also be mediated by the K^+-H^+ symporter or facilitated by a voltage-independent channel (Urban and Bystrzejewska-Piotrowska 2003; White and Broadley 2000). Thus, the local vegetables containing detectable amounts of Cs may be candidates for phytoremediation plants to effectively remove Cs from humus-Cs complex. At least, *L. indica* and *C. papaya* in peat soils, and probably *Cosmos caudatus* cultivated in mineral soil in Bogor, are likely to be one of high Cs-absorbable plants. Hence, some tropical peatland-adaptable plants may have a high potential as phytoremediators for radioactive Cs from humus-rich soils, as desired in Fukushima, Japan (Baba *et al.* 2016).

Conclusion

Selective accumulation of Al rather than Fe in some local vegetables (e.g. *Nauclea* sp. and *L. indica*), but more importantly, excessive accumulation of Mn in *S. androgynous* and *L. indica*, should be noted (Table 4). Thus, this study strongly suggests that the traditional food culture of the local community in Central Kalimantan where they utilize young leaves of the wild, edible ferns is a sort of wisdom of living in the Histosol land to overcome chronic deficiency of essential micro-elements. Such local food materials should be re-investigated more carefully for valuable resources for local communities.

Acknowledgments

We thank for PARE program provided by Hokkaido University (to D.R.).

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