Copper accumulation by *Polygonum microcephalum* D. Don and *Rumex hastatus* D. Don from copper mining spoils in Yunnan Province, P.R. China

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Abstract A survey was made of copper mining spoils in Yunnan Province, southwest China. *Polygonum microcephalum* and *Rumex hastatus* were found to grow extensively on copper mining spoils in Yunnan Province as representatives of typical high-elevation copper flowers. Plants and their associated soil samples collected from several copper mines in the Province were analyzed for copper. It is found that both plant species can grow well on mining spoils rich in copper but with medium nutrient supply. *P. microcephalum* accumulated more copper in its organs than *R. hastatus.* The copper concentration in the roots of both species tended to increase with copper increase in the substrates. However, the tendency for the levels of copper in the leaves of both species to increase linearly with soil copper increase is not clear. This study suggests that both species may have some potential for phytostabilization of metal-contaminated soils and for biogeochemical prospecting.

Keywords Copper accumulation · *Polygonum microcephalum* · *Rumex hastatus*

Introduction

An investigation of plant natural colonization of the copper mining spoils is of interest because of its possible application to phytostabilization, revegetation, and study of tolerance mechanism. Much research has been conducted on vegetation associated with copper mineralization outside China, especially in south-central Africa (Reilly 1967; Reilly and Stone 1971; Malaisse and others 1978; Baker and others 1983). Many plants were found to be tolerant of metal toxicity (Cox and Hutchinson 1979). However, less work on plants growing on soils rich in copper and other heavy metals appears to have been done in China, especially in terms of the relation of soil metals to heavy-metal uptake by these plants (Tang and others 1999). There are many plants that grow on mining soils and have been used for mineral exploration by geologists for decades in China (Tang and others 1996, 1999). Because of China's vast land, with its various range of climate and geographic features, plants growing in the same metal-contaminated soils but with different climatic and geographic characteristics are different. Thus, it is necessary to investigate the plants growing in different geographic belts with different climatic characteristics. In 1996 and 1997, the authors conducted extensive research on the vegetation growing on the copper and zinc mining spoils along the middle and lower streams of the Yangtze River. As a result of the investigation, several typical and dominant plant species were discovered in the district including *Elsholtzia haichowensis* Sun., *Commelina communis* Linn., *Rumex acetosa* Linn. (Tang and others 1999) and *Ambrosia artemisiifolia* Linn. (S.R. Tang unpublished data). In this study, species dominantly growing on copper mining spoils and soils in a high elevation district such as Yunnan Province were investigated. The objective was to identify the dominant species in those areas and find the relationship between copper uptake in these plants and their supporting substrates. Two dominantly growing plants including *Polygonum microcephalum* and *Rumex hastatus* were identified as a result of the survey. In this paper, the authors present the data pertaining to these species in terms of the distribution, ecological habitat, copper accumulation, and relationships with their growing substrates.

Received: 12 January 2000 / Accepted: 3 October 2000
Published online: 15 February 2001

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Climate and distribution of *P. microcephalum* and *R. hastatus*

The studied areas are located in the middle of Yunnan Province, southwest China (Fig. 1), belonging to the Middle Asian tropical plateau monsoon-type climate. The areas are characterized by a high elevation of >1,300 m with an undulating relief. The year is divided into two main

DOI. 10.1007/s002540100256

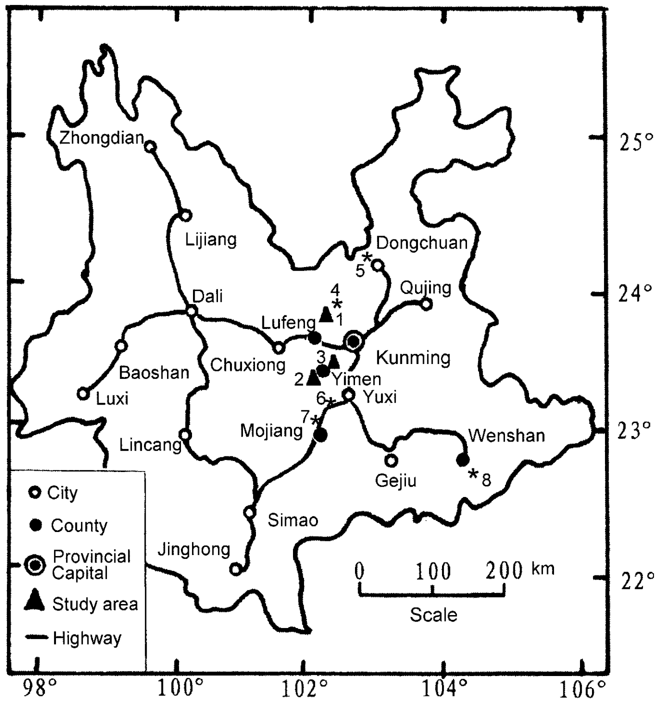


Fig. 1
Location of study area in Yunnan Province, southwest China. The studied species commonly occur in high elevation mining spoils of the Province such as Dongchuan, Wenshan, Yimen, Wudian, and Qinglongchang. Numbers *1*, *2*, and *3* represent Dameichuang copper mine, Lufeng county; Xiaoliuzhi copper mine, and Tongchang copper mine, Yimen county, respectively whereas *4*, *5*, *6*, *7*, and *8* denote the occurrence of both species in those areas

seasons: wet and dry. The wet season lasts from mid-April to early September, with heavier rains. The yearly average rainfall is ~915 mm with maximum value of 1,444 mm and minima of 622 mm. The average temperature for the whole year is ~16 °C with an average monthly temperature of above 5 °C and about 260 days without frost.

Species found on the copper mining sites include *R. hastatus*, *P. microcephalum*, *Elsholtzia rugulosa* Hemsl., and *Erioscirpus comosa*. Since the latter two species are less common in the copper mining areas, they are not considered in detail in the present study. The first two species are very common in the copper mining spoils of the Province forming a dominant population and may be suitable for phytostabilization purposes. Therefore, they were the main species investigated.

Both *P. microcephalum* and *R. hastatus* are called by local geologists "copper grass" (Tongcao) or "copper flower" (Tonghua) because they appear to be confined to substrates rich in copper. However, in different localities there are different meanings. For example, "Tongcao" at Xiaoliuzhi, Yimen county, is referred to as *R. hastatus* whereas at Da Meichuang, Lufeng county, it is referred to as *P. microcephalum*. By the nickname, one can guess that they can be tolerant to at least one metal – copper.

P. microcephalum (Polygonaceae family) is a perennial herb, reaching 1 m in height, flowering from late May through July, and with nearly perpendicular stems. This species commonly occurs at the high elevation (>1,700 m) mining areas of Yunnan province, southwestern China. It grows in places where the substrates contain copper. Sometimes it can be found growing vigorously along the soil walls of local homes. It grows better in places with a greater water supply and more clay in the soils (silty-clay loam to clay loam consisting of 17–18% sand, 29–35% clay, and 47–54% silt, USDA textural classification, see Table 1) resulting from strong rock weathering and containing a high concentration of copper, suggesting that it is a copper-loving, hydrophilic and clay-loving plant.

R. hastatus (Polygonaceae family) is also a perennial herb with growth up to 140 cm, flowering from early July to late

Table 1
Average analytical results of the plants and associated soils from the root zone. Number in parentheses represents sample number for analysis

Species	*P. microcephalum*		*R. hastatus*		
Locality	Dameichuang	Tongchuang	Dameichuang	Xialiuzhi	Tongchang
Plants					
Dry weight biomass (g)	15.3 ± 5.9 (14)		52.75 ± 49.66(26)		
Cu in roots (mg/kg)	491 ± 782 (14)		33 ± 23 (26)		
Cu in stems (mg/kg)	110 ± 72 (14)		42 ± 42 (26)		
Cu in leaves (mg/kg)	133 ± 94 (14)		45 ± 32 (26)		
Soils (mg/kg)					
Cu (HNO_3 extracted)	1494 ± 1603(14)		2105 ± 1664(26)		
Cu (NH_4-EDTA extracted)	363 ± 350(14)		284 ± 290(26)		
C organic (%)	1.91 ± 0.48 (14)		1.60 ± 0.67 (26)		
[a]N (mg/kg)	20.3 ± 8.2 (5)		53.5 ± 33.8 (10)		
[b]P (mg/kg)	18.9 ± 7.0 (5)		23.5 ± 14.6 (10)		
[c]K (mg/kg)	43 ± 14 (6)		40 ± 15 (14)		
pH (water)	7.06 ± 0.54 (14)		7.72 ± 0.89 (26)		
pH ($CaCl_2$)	6.46 ± 0.82 (14)		7.12 ± 0.68 (26)		
Soil textures (4)	Sand % 17–18; Clay % 29–35; Silt % 47–54		Not determined		

[a] Exchangeable nitrogen
[b] Phosphorus soluble in sodium bicarbonate
[c] Exchangeable potassium

October. This species is very common in the copper mining spoils of the Yunnan province. In most places, it forms the only dominant population. In a few cases it grows side-by-side with *P. microcephalum*. This plant species produces large amounts of dry matter and appears very healthy even when its substrate consists mainly of fragments of rocks and little water. It has a very long root, up to 92 cm, as observed in the field. The species can grow well on any substrate that contains copper.

Materials and methods

Plants of the two dominant species, *P. microcephalum* and *R. hastatus*, and their associated soils from the root zone were collected from 14–28 July 1999 from several copper mines, including Da Meichuang copper mine, Lufeng county, Xiaoliuzhi copper mine and Tongchang copper mine, Yimen county, which are situated ~80 km west, 120 km southwest, and 100 km southwest, respectively, of the provincial capital Kunming, Yunnan Province (Fig. 1). Samples were collected and stored in plastic bags. Fresh plant samples were washed with tap water, rinsed several times with deionized water after return to the laboratory to avoid contamination, sorted into leaves, stems, and roots, oven-dried at 80 °C, and recorded for dry weight. Ground subsamples of each plant (~0.2 g on a dry weight basis) were wet-ashed in 10 ml of 2 M HNO_3. The resulting solutions were filtered and analyzed for Cu by atomic absorption spectrometry (AAS) using a Hitachi 180-80 instrument. Blank determinations were also performed for comparison. Soil samples were taken from the base of each plant from 0–20 cm depth. The soils were air-dried, sieved (60 mesh), and stored in paper bags for chemical analysis. Subsamples (~1 g) of this sieved material were weighed and digested with 10 ml of the 2 M HNO_3 (Geiger and others 1993). Digests were filtered. The other soil subsamples (~1 g) were extracted with 10 ml of 0.05 M NH_4–EDTA (pH≈7) by shaking for 30 min at 25 °C (Homer and others 1991). After filtration, the resulting extractants together with the digests were analyzed for Cu. Organic carbons in the substrates were determined following a modified Mebius procedure (Nelson and Sommers 1982). The concentrations of N, P, and K were determined with a microdiffusion method (Bremner 1965), 0.5 mol/l $NaHCO_3$ (pH 8.5) extraction methods (Anderson and Ingram 1993), and an NH_4–OAc extraction method (Pratt 1965). The pH values were determined using a soil:water ratio of 1:2.5. The average analytical results are given in Table 1. Soil textures for *P. microcephalum* were determined following the procedure given in Gee and Bauder (1986).

Results and discussion

Table 1 shows mean values and standard deviations for copper concentrations in plants and their associated soils from the root zone. Both plant species can survive well on the copper mining spoils but there is a larger difference in the uptake of copper although they belong to the same family (Table 1). *P. microcephalum* has higher concentrations of copper in the roots, stems, and leaves, ranging from 36–2,854, 14–244, and 9–332 mg/kg, respectively (on a dry weight basis), and averaging 491±782, 110±72, and 133±94 mg/kg, respectively. *R. hastatus* contain lower concentrations of copper in its organs with copper concentration ranging from 4–74, 3–145, and 2–130, and averaging 33±23, 42±42, and 45±32 mg/kg in the roots, stems, and leaves, respectively. This suggests that both species can accumulate some copper in their organs when they grow on copper contaminated soils. Copper concentration in the leaves of *P. microcephalum* is higher than that in the leaves of *R. hastatus*, indicating that *P. microcephalum* can accumulate more copper than *R. hastatus* (Fig. 2). More accumulation of copper by *P. microphalum* than *R. hastatus* implies that the former is more tolerant of copper toxicity than the latter. *P. microcephalum* accumulated much more copper, whereas *R. hastatus* in the same conditions contained only a little more copper than would be found in plants growing on non-mineralized soils. This suggests that more Cu is excluded from the aerial parts of *R. hastatus* than *P. microcephalum* growing on the heavily copper-contaminated soils. Reilly (1967) found a similar phenomenon for copper in *Trachypogon spicatus* and *Becium homblei.*

Extracted copper concentrations (from 2 mol/l HNO_3) in the substrates supporting the growth of *P. microcephalum* ranged from 181–6,713 mg/kg, and averaged 1,494±1,603 mg/kg (on a dry weight basis). It was a similar case for *R. hastatus*. Its extracted copper (from 2 mol/l HNO_3) ranged from 67–4,125, and averaged 2,105±1,664 mg/kg. Copper concentrations extracted with 0.05 mol/l NH_4–EDTA (pH≈7.0) from the soils supporting both species are also high (Table 1). This indicates that all the substrates were heavily contaminated with copper and may be highly toxic to normal plant populations as reported in the literature (McNeilly and Bradshaw 1968; McNeilly and Johnson 1978), but the investigated species can well survive on copper contaminated soils. The other features of the substrates for the growth of both species is that they all lack fertility as confirmed by low soil organic carbon (Table 1). The concentrations of inorganic forms of nitrogen, phosphorus, and potassium in the substrates, supporting both species, are not high (Table 1). The pH values of the soils supporting the growth of *P. microcephalum* and *R. hastatus*, measured in 0.01 mol/l $CaCl_2$ and in water, are near-neutral, ranging from 4.65–7.29 and 5.01–7.61, and averaging 6.46±0.82 and 6.78±0.75, respectively. The above lines of evidence show that both species can survive on neutral soils with a high concentration of copper and only a medium nutrient supply.

There were larger differences in the copper contents of the plant parts of *P. microcephalum* than *R. hastatus* for a given concentration of copper in the soil (Fig. 2). For the roots of both species there was a similar relationship between the copper contents of roots and soils. The copper

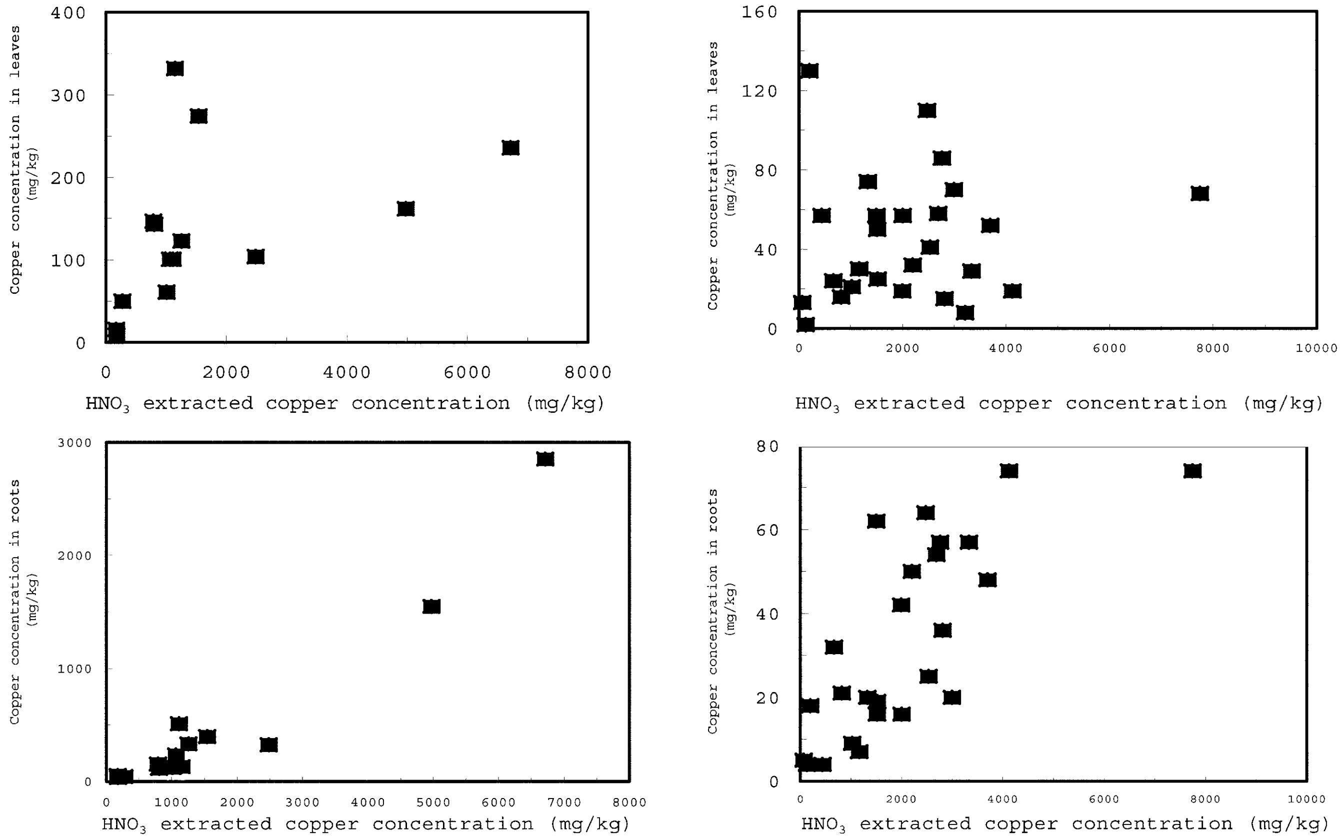
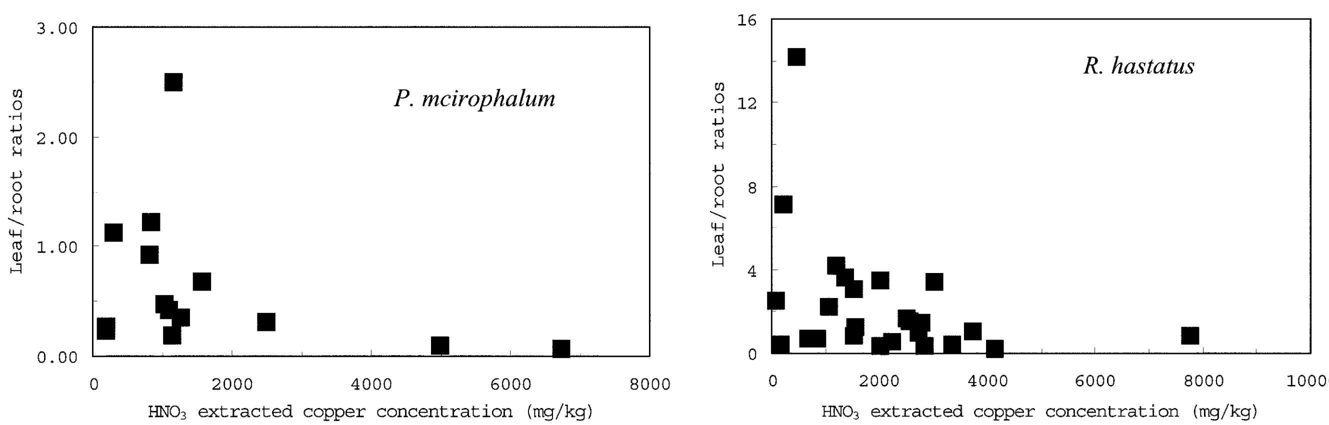


Fig. 2
Copper concentration (mg/kg) in plant organs of **a** *P. microcephalum* (two on the *left side*), and **b** *R. hastatus* (two on the *right side*) as a function of copper concentration (mg/kg) measured in the substrates

concentration in the roots of *P. microcephalum* and *R. hastatus* tended to increase with an increase in copper in the substrates. However, the tendency for the levels of copper in the leaves of both species to increase linearly with increase in concentration of soil copper is not clear (Fig. 2). Leaf/root ratios exhibit a decreasing tendency with 2 mol/l HNO_3 extracted copper concentration in the substrates (Fig. 3). Leaf/root ratios were proposed by Baker (1981) to describe mechanisms by which plants uptake and transport metals when they grow on metal-contaminated soils. Figure 3 also suggests that *P. microcephalum* is more likely to be an accumulator, whereas *R. hastatus* is an excluder on the basis of comparing the leaf/root ratios of both species. Implicit in the investigation is that two species with different uptake and transport characteristics grow side-by-side on copper-contaminated soils. A negative relationship between contents of organic carbons and 2 mol/l HNO_3 extracted copper concentration in the substrates can be established for both species (Fig. 4). This evidence suggests that both species may have some potential for phytostabilization of copper-contaminated soils and for the exploration of copper ores.

Fig. 3
Leaf/root ratios against 2 mol/l HNO_3 extracted copper concentration in the substrates



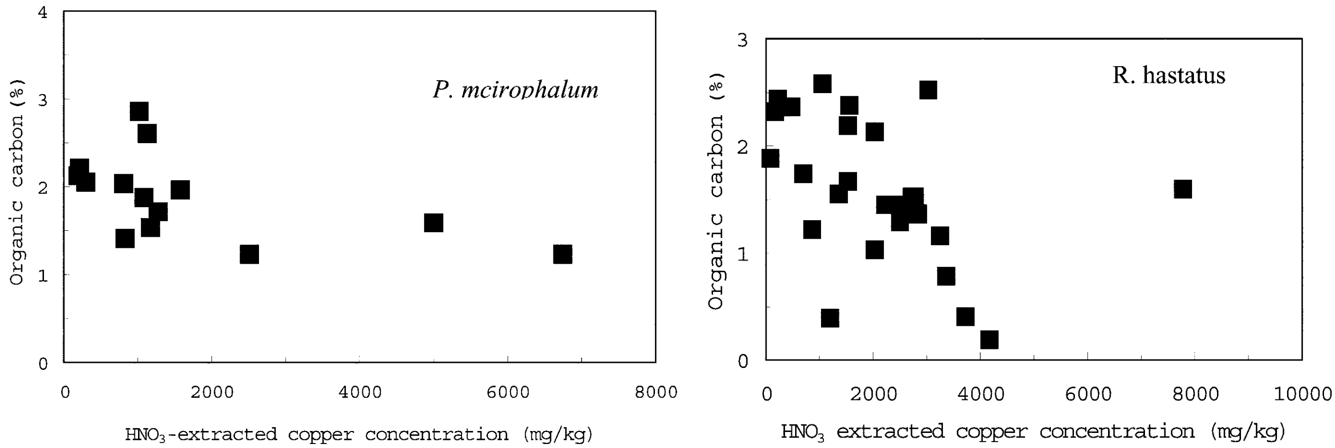


Fig. 4
Relationship between contents of organic carbons and 2 mol/l HNO_3 extracted copper concentration in the substrates

Copper-tolerant flowers reported in the literature are predominantly in the families of Lamiaceae (Reilly 1967; Reilly and Stone 1971; Brooks and others 1978; Malaisse and others 1978; Morrison and others 1981; Homer and others 1991; Tang and others 1999), Caryophyllaceae (Baker and others 1983; Schat and others 1993), Poaceae (Lin Wu and others 1975; Cox and Hutchinson 1979), and Portulacaceae, Fabaceae, Anacardiaceae, and Verbenaceae (Tiagi and Aery 1986). In China it is found that, besides the families Commelinaceae and Lamiaceae (Tang and others 1999), there is another family – Polygonaceae – which can also survive on copper-contaminated soils and can accumulate copper to some degree. In our previous paper, we reported that *R. acetosa* can survive on copper-contaminated soils along the middle and lower streams of the Yangtze River and accumulates copper to a great degree. This species is representative of vegetation that grows at low elevation areas. In contrast, species surviving in high elevation copper-contaminated soils in Yunnan Province are characterized by the appearance of *R. hastatus* and *P. microcephalum*, which both belong to the Polygonaceae family. The difference in vegetation that occurs on copper-contaminated soils observed in high elevation areas and low elevation areas may be due to different sea-level and geographic belts. Reilly (1967) reported that *Trachypogon spicatus* could grow on soils containing 7,250 mg/kg of copper but did not accumulate the metal. Its leaves had only 15 mg/kg of copper. It is a similar case for *R. hastatus*, which is an efficient excluder.

Conclusion

P. microcephalum and *R. hastatus* are widely distributed in Yunnan Province and are representative copper-tolerant flowers of high-elevation districts, showing a completely different plant community from that growing in low-elevation copper-contaminated soils in China. These study results show that both species have an ability to accumulate copper and survive on copper-contaminated soils with a medium nutrient supply, which shows a strong tolerance to stress environments. These features make them suitable for further investigations into the relationship between heavy metal accumulation and soil conditions. Because of its ability to survive on copper-contaminated soils with a medium nutrient supply, they may have some potential for phytostabilization of copper-contaminated soils and copper-mining spoils. Their close association with copper in the soils suggests that they can also be used as indicators for the exploration of copper ores in forest areas.

Acknowledgements The authors thank Prof. Wu Zhengyi (Wu Chengyi) and Dr. Peng Hua, both from the Kunning Institute of Botany, Academia Sinica, and Prof. Fang Yunyi of the Department of Biology, College of Biological Sciences, Zhejiang University, for their identification of the studied plants. Special thanks also go to Prof. Robert R. Brooks from the Department of Soil Science, Massey University, Palmerston North, New Zealand for reviewing the initial manuscript. This research work was jointly supported by the National Natural Science Foundation of China (No. 39600085), "973" project from the Ministry of Science and Technology, P.R. China (NKBRSFG 1999011808), and the Provincial Natural Science Foundation of Zhejiang.

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