A fern that hyperaccumulates arsenic

A hardy, versatile, fast-growing plant helps to remove arsenic from contaminated soils.

Contamination of soils with arsenic, which is both toxic and carcinogenic, is widespread[1]. We have discovered that the fern *Pteris vittata* (brake fern) is extremely efficient in extracting arsenic from soils and translocating it into its above-ground biomass. This plant — which, to our knowledge, is the first known arsenic hyperaccumulator as well as the first fern found to function as a hyperaccumulator[2] — has many attributes that recommend it for use in the remediation of arsenic-contaminated soils.

We found brake fern growing on a site in Central Florida contaminated with chromated copper arsenate (Fig. 1a). We analysed the fronds of plants growing at the site for total arsenic by graphite furnace atomic absorption spectroscopy. Of 14 plant species studied, only brake fern contained large amounts of arsenic (As; 3,280–4,980 p.p.m.). We collected additional samples of the plant and soil from the contaminated site (18.8–1,603 p.p.m. As) and from an uncontaminated site (0.47–7.56 p.p.m. As). Brake fern extracted arsenic efficiently from these soils into its fronds: plants growing in the contaminated site contained 1,442–7,526 p.p.m. arsenic and those from the uncontaminated site contained 11.8–64.0 p.p.m. These values are much higher than those typical for plants growing in normal soil, which contain less than 3.6 p.p.m. of arsenic[3].

As well as being tolerant of soils containing as much as 1,500 p.p.m. arsenic, brake fern can take up large amounts of arsenic into its fronds in a short time (Table 1). Arsenic concentration in fern fronds growing in soil spiked with 1,500 p.p.m. arsenic increased from 29.4 to 15,861 p.p.m. in two weeks. Furthermore, in the same period, ferns growing in soil containing just 6 p.p.m. arsenic accumulated 755 p.p.m. of arsenic in their fronds, a 126-fold enrichment. Arsenic concentrations in brake fern roots were less than 303 p.p.m., whereas those in the fronds reached 7,234 p.p.m.

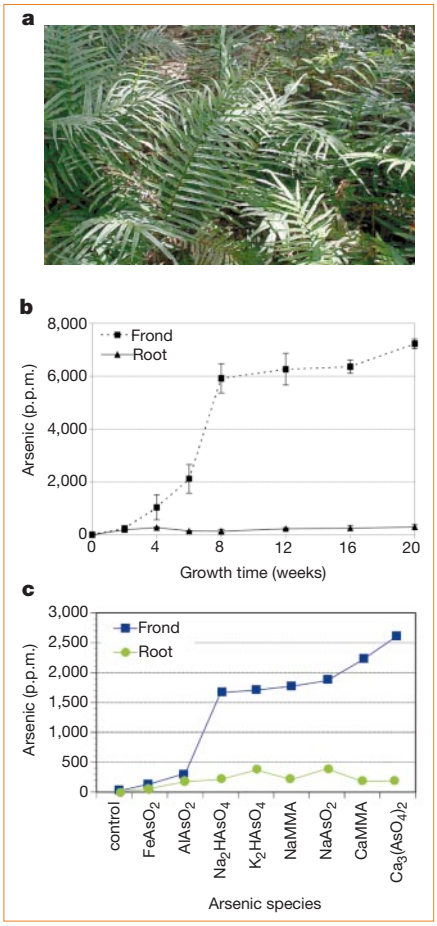

Figure 1 Arsenic concentrations in brake fern growing in arsenic-contaminated soils. **a,** Brake fern growing on an abandoned wood-preservation site contaminated with chromated copper arsenate (CCA); **b,** arsenic concentrations in brake fern after 20 weeks' growth in a CCA soil containing 97 p.p.m. As; and **c,** arsenic concentrations in brake fern after 18 weeks' growth in soil spiked with 50 p.p.m. As of various species. Brake fern plants grown in the laboratory were transferred to 2.5-litre pots (one plant per pot, with four replicates) containing 1.5 kg soil to determine arsenic-uptake changes with time and the arsenic species. NaMMA, monosodium methylarsonate; CaMMA, calcium acid methanearsonate.

(Fig. 1b). Addition of 100 p.p.m. arsenic significantly stimulated fern growth, resulting in a 40% increase in biomass compared with the control (data not shown).

After 20 weeks of growth, the plant was extracted using a solution of 1:1 methanol:water to speciate arsenic with high-performance liquid chromatography–inductively coupled plasma mass spectrometry. Almost all arsenic was present as relatively toxic inorganic forms, with little detectable organoarsenic species[4]. The concentration of As(III) was greater in the fronds (47–80%) than in the roots (8.3%), indicating that As(V) was converted to As(III) during translocation from roots to fronds.

As well as removing arsenic from soils containing different concentrations of arsenic (Table 1), brake fern also removed arsenic from soils containing different arsenic species (Fig. 1c). Again, up to 93% of the arsenic was concentrated in the fronds. Although both $FeAsO_4$ and $AlAsO_4$ are relatively insoluble in soils[1], brake fern hyperaccumulated arsenic derived from these compounds into its fronds (136–315 p.p.m.) at levels 3–6 times greater than soil arsenic.

Brake fern is mesophytic and is widely cultivated and naturalized in many areas with a mild climate. In the United States, it grows in the southeast and in southern California[5]. The fern is versatile and hardy, and prefers sunny (unusual for a fern) and alkaline environments (where arsenic is more available). It has considerable biomass, and is fast growing, easy to propagate, and perennial.

We believe this is the first report of significant arsenic hyperaccumulation by an unmanipulated plant. Brake fern has great potential to remediate arsenic-contaminated soils cheaply and could also aid studies of arsenic uptake, translocation, speciation, distribution and detoxification in plants.

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Table 1 Arsenic concentrations in brake fern

Treatments	*Soil arsenic (p.p.m.)*	*Plant arsenic (p.p.m.)*	
		2 weeks	*6 weeks*
Control	6	755	438
As-contaminated soil*	400	3,525	6,805
Low As†	50	5,131	3,215
Medium As†	500	7,849	21,290
High As†	1,500	15,861	22,630

Brake fern plants, collected from several uncontaminated sites (they are not commercially available), were planted in 2.5-litre pots containing 1.5 kg of soil (one plant per pot with four replicates) and grown for six weeks.
*Arsenic-contaminated soil was collected from the site where brake fern was discovered.
†Artificially contaminated soil was spiked with three levels of water-soluble potassium arsenate.

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