Revealing the pathways of cadmium uptake and translocation in cacao trees (*Theobroma cacao* L.): a ^{108}Cd pulse-chase experiment

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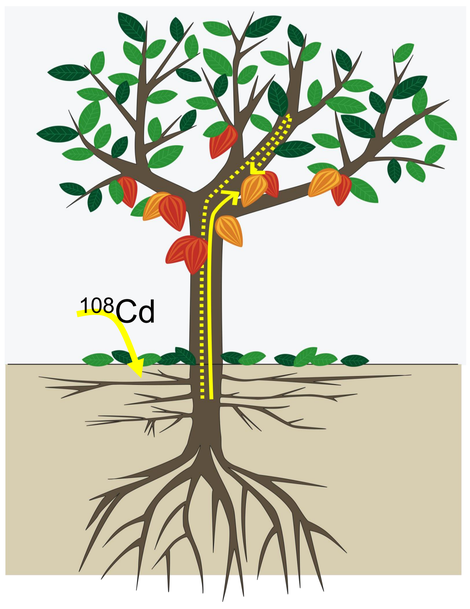
Context and objectives

- High cadmium (Cd) uptake in cacao limits cacao production in Latin America
- Can bean Cd be lowered by breeding and or grafting? This is difficult to predict without information on the pathways (xylem or phloem) of Cd within the plant
- A stable isotope (^{108}Cd) pulse-chase experiment was set up to identify the pathways of Cd loading into cacao nibs.

Methodology

- Two mature trees selected in Ecuador (December 2020).
- Leaf litter removed in a 2 m radius around the trunk of both trees, ^{108}Cd stable isotope applied in 10 mm irrigation, litter placed back
- Periodic soil and plant sampling over 548 days after spiking, analyses for Cd isotopes with ICP-MS



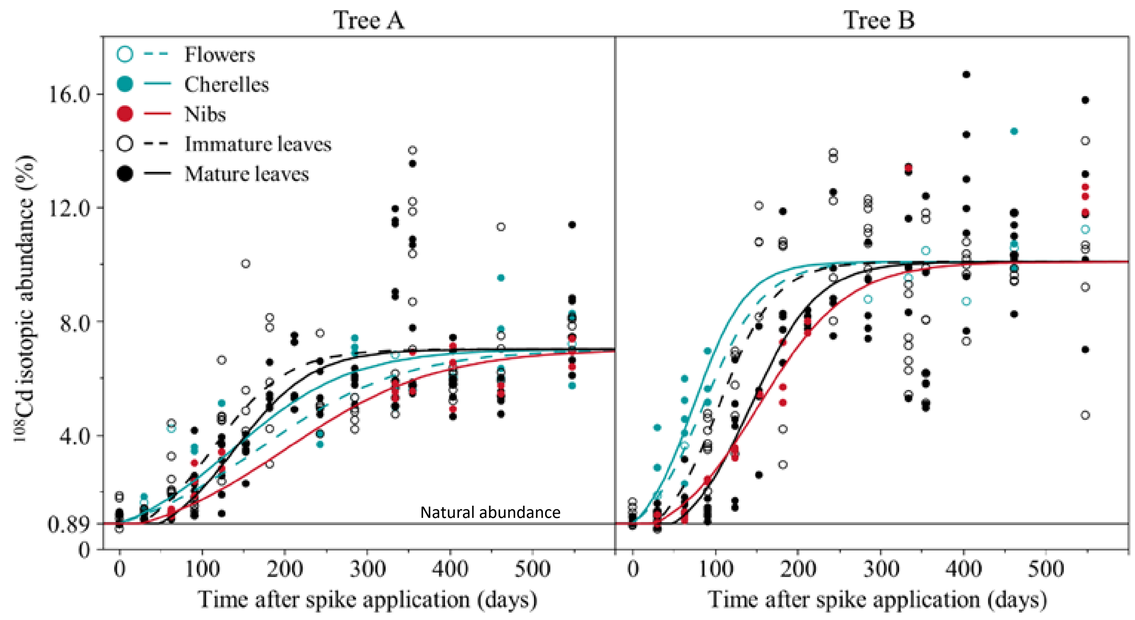
Results

- Topsoil has neutral pH (6.5) and low total Cd
- Plant Cd concentrations lower than nationwide values and nib Cd concentrations are below limits for trade
- Cd concentrations rank nib<young leaves<old leaves

Average dry weight based Cd concentrations in plant samples collected during the 548 days of the experiment. Letters denote significant differences within one column based on Tukey's honestly significant difference test (P-value < 0.05).

	Cd (mg kg^{-1})	
	Tree A	Tree B
Flowers	0.40 A	0.51 A
Immature leaves	0.29 B	0.38 B
Mature leaves	0.39 A	0.50 A
Nibs	0.12 C	0.20 C
Cherelles	0.33AB	0.37 B
Soil*	0.17 ± 0.06	0.14 ± 0.03

** mean and standard deviation for 0-5 cm topsoil (n=4), soil Cd concentrations were **not** affected by ^{108}Cd spiking.*



- Gradual rise in the ^{108}Cd isotopic abundance with rates: immature leaves > mature leaves > nibs
- Half of the equilibrium ^{108}Cd IA reached in the nibs significantly later than in for mature and immature leaves
- The rather slow rise in the ^{108}Cd IA in the nibs compared to the leaves suggests that Cd in cacao nibs likely originates from phloem-redistribution from the stem, branches or mature leaves and not from direct root-to-nib transport via the xylem.

Estimated time to reach half of background corrected equilibrium Isotopic Abundance (days)

	Tree A		*Tree B*	
	Estimate	95% CL	Estimate	95% CL
Immature leaves	124	104 – 145	111	98 – 124
Mature leaves	152	131 – 173	**151***	137 – 164
Flowers	191	67 – 316	93	-25 – 210
Cherelles	156	91 – 222	80	61 – 99
Nibs	**225***	152 – 299	**163***	135 – 190

* Values significantly different (based on 95% CL) from that of the immature leaves.

Conclusion and interpretation

- Nib Cd is unlikely derived from direct xylem transport from the roots but rather from leaves (loaded somewhat faster) or the woody tissues (unsampled).
- Recent work (Blommaert et al. 2023) suggests that Cd in cacao originates from phloem- and xylem-mediated redistribution from the stems and branches of the tree
- Data indirectly suggests that nib Cd is more under control of the scion than of the rootstock. This now awaits long term grafting experiments

Reference
Blommaert et al. (2023). From soil to cacao bean: Unravelling the pathways of cadmium translocation in a high Cd accumulating cultivar of *Theobroma cacao* L. *Frontier Plant Sci.* in press. DOI 10.3389/fpls.2022.1055912