Crop plants screened and certified for low content of potential toxic elements

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Context

Plants cultivated in polluted environment can absorb Potential Toxic Elements (PTEs) and translocate them into their organs. As a consequence, PTEs can be concentrated into the edible parts of the plant, at concentrations that can be harmful for human health and animal health, which can in turn spread the PTEs into the ecological food chain. Ideally, none should grow crops on polluted soil. However, this happens. Due to human activities of which the impacts are unknown, many soils contain substances which can be potentially toxic if they enter the food chain through crops. This guideline aims to disseminate applied knowledge from expertise of the PlantMetals Cost Action members to the applied sector as improved breeding and agricultural management strategies to enhance nutritive value of crops in the current context of climate change while reducing environmental pollution. The creation of a fully referenced database of agricultural plants screened for their low accumulation of PTEs starting from the basic criteria illustrated in Figure 1 is a first step in initiating the knowledge transfer into practical instructions.

Crop species

Potential accumulation of PTEs in crops is long known (see Baker et al. 1994; Ebbs and Kochian 1997). Main examples are *Brassicaceae*, particularly several *Brassica* such as *B. nigra*, *B. oleracea*, *B. juncea*, *B. napus*, but also *Raphanus sativus*, which can accumulate various PTEs at very high concentrations in their tissues when grown on polluted soils (Chaney et al. 1997), thus resulting in similar or even higher offtake of pollutants than hyperaccumulators. Other well studied crop plants know to (hyper)accumulate PTEs are sunflower (*Helianthus annuus*), maize (*Zea mays*) and species of the *Poaceae* family belonging to *Festuca*, *Lolium*, and *Hordeum vulgare, Sorghum bicolor,* species of the *Fabaceae* family such as *Phaseolus vulgaris*, and *Medicago sativa*. An ever increasing number cropped plants capable of accumulating PTEs is reported in publications. A list of major crop plants that accumulate or hyperaccumulate PTEs is reported in Table 1.

Table 1. Example of crop plant that accumulate or hyperaccumulate PTEs

Family				**Species**				
Asteraceae	*H. annuus*							
Fabaceae	*G. max*	*P. vulgaris*	*M. sativa*	*P. sativum*				
Brassicaceae	*B. juncea*	*B. napus*	*R. sativus*	*B. carinata*	*S. alba*			
Poaceae	*Z. mays*	*Lolium spp.*	*Festuca spp.*	*H. vulgare*	*Sorghum spp.*	*Triticum spp.*	*A. sativa*	*O. sativa*

Amongts PTEs, cadmium (Cd) is one of the most translocated metal from the soil to the above ground parts of the crops. It is also one of the most hazardous pollutant which can cause human and animal deseases and organ damages.

Strategies to prevent or mitigate PTEs uptake by crop plants

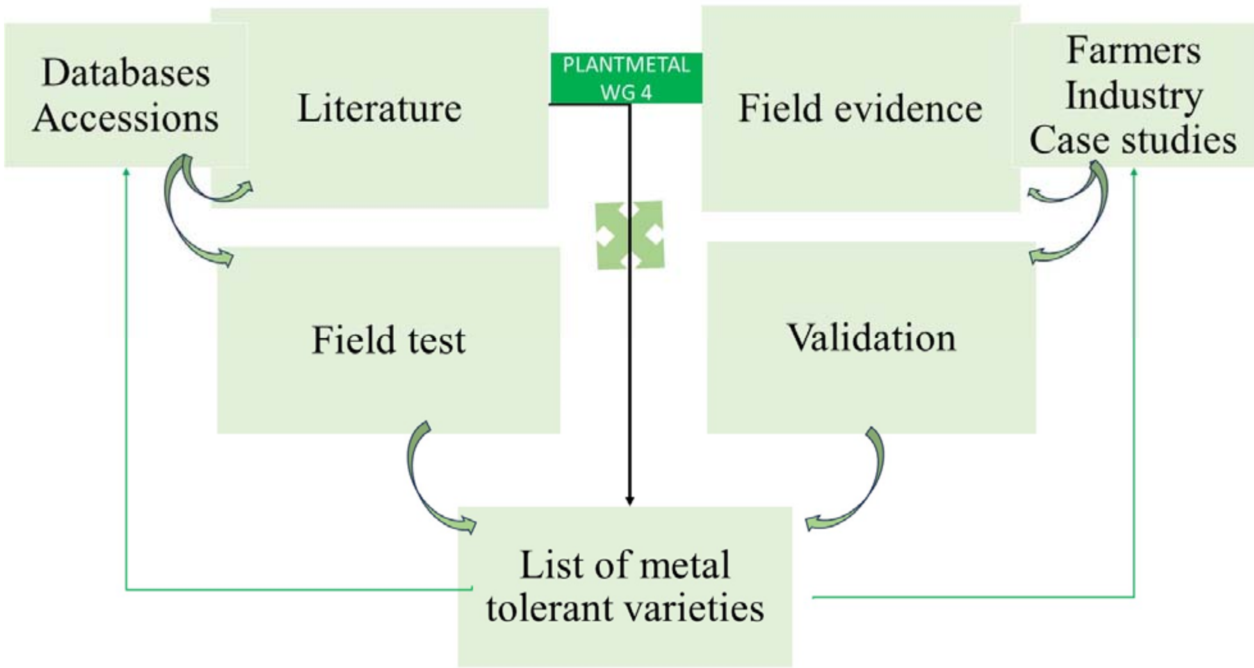
Plant breeding and plant selection

Plant breeding and molecular genetics have been used for controlling the plant capacity to absorb and translocate the PTEs in above ground plant parts, and the identified genes involved in uptake and detoxification of PTEs have been studied with the aim to understand and reduce the overall potential risks of cultivating plants in polluted environments.

Soil amendment for PTEs stabilization

To reduce the human exposure to potential toxic elements (PTEs) due to transfer from soil and water to plants and to the food chain, two main approaches are currently used: immobilization and stabilization in soil through physical and chemical methods, or screening for crop varieties that are tolerant or excluders, and take up low amounts of PTEs. Indeed, the scientific literature shows that different varieties of the same cultivated plant species exhibit significant differences in the uptake and translocation of PTEs. Differences are genetically based, but the level of metal enrichment of plant biomass and primary crop produced also depend on the plant nutritional and health status, soil physical, chemical and biological properties, agronomic practice, type origin and complexity of the environmental pollution, and other site-specific environmental factors. The addition of specific soil product that can, for instance, modify the soil pH to reduce the metal mobility in the soil and for plant translocation or can form non soluble precipitate with the metal can help to mitigate the PTEs uptake by crop plants.

Figure 1. workflow of the PLANTMETALS database of metal tolerant agricultural plants.



The database will be initiated by the analysis and classification of major world crops and it will be enriched from the continued literature search and from the analysis of case studies from the worldwide interaction between farmers, academia, and Agricultural and Environmental Agencies. The initial work will concern the accumulation level of Cd, one of the priority PTEs to address due to its bioaccumulation in the food chain and its toxicity, into the most commercially widespread varieties and lines of major crop plants such as maize (*Zea mays* L.), wheat (*Triticum aestivum* L.) and rice (*Oryza sativa* L.).

The screening of low metal varieties has several advantages:

1) It is genetically based, therefore it ensures the low metal uptake under different pedological, climatic, and management conditions, being implementable under various conditions
2) It is sustainable because does not require specific soil interventions
3) It produces low PTEs enriched biomass which can be safely used for eating under certain conditions and non-edible purposes such as bioenergy purposes without spreading of PTEs into the environment.

The plant screening approaches can be conducted at different scales and for different aims. Concerning the scales, laboratory/phytotron/greenhouse levels are suited for selecting and testing the genetic characteristics of the lines, and understand the mechanisms of low metal uptake, translocation and concentration, whereas open field/experimental farm/commercial farm scales are more suited for evaluating the crop productivity and primary food safety of the tested lines.

Rice, wheat and maize low Cd varieties are presented in Tables 1 and 2 as preliminary data and knowledge which can be used to fulfil the database.

Table 1. Examples of rice varieties with low cadmium content screened and certified in Hunan Province in 2016. From Long, H.Y., Feng, G.F. & Fang, J. In-situ remediation of cadmium contamination in paddy fields: from rhizosphere soil to rice kernel. Environ Geochem Health 46, 404 (2024). https://doi.org/10.1007/s10653-024-02099-9.

Type	**Variety**	**Breeding unit (first completion unit)**
Hybrid rice	Zhu Liang You 729	Hunan Rice Research Institute
Hybrid rice	Zhu Liang You 706	Hunan Longping Gaoke Nongping Seed Industry Co., Ltd
Hybrid rice	Liang You Zao 17	Hunan Jinjian Seed Industry Technology Co., Ltd
Hybrid rice	Zhu Liang You 211	Hunan Yahua Seed Industry Research Institute
Hybrid rice	Zhu Liang You 15	Original seed farm in Hejiashan, Hunan Province
Hybrid rice	Tan Liang You 215	Xiangtan Institute of Agricultural Sciences
Conventional variety	Xiang Zao Xian 42	Hunan Rice Research Institute
Hybrid rice	Shen You 9595	Yuan Longping Agricultural High-tech Co., Ltd
Hybrid rice	C Liang You 386	Hunan Agricultural University
Hybrid rice	Y Liang You 19	Hunan Longping Seed Industry Co., Ltd

Type	Variety	Breeding unit (first completion unit)
Hybrid rice	C Liang You 651	Hunan Fengyuan Seed Industry Co., Ltd
Hybrid rice	C Liang You 755	Hunan Agricultural University
Hybrid rice	Shen Liang You 5814	National Hybrid Rice Engineering Technology Research Center
Hybrid rice	Jing Liang You Hua Zhan	Hunan Yahua Seed Industry Research Institute
Hybrid rice	De Xiang 4103	Rice and Sorghum Research Institute, Sichuan Academy of Agricultural Sciences
Hybrid rice	Jian Liang You Hua Zhan	Hunan Jinjian Seed Industry Technology Co.,.Ltd
Hybrid rice	Lu You 9803	Rice and Sorghum Research Institute, Sichuan Academy of Agricultural Sciences
Hybrid rice	C Liang You 87	Hunan Agricultural University
Hybrid rice	C Liang You 7	Hunan Agricultural University
Hybrid rice	Feng Yuan You 272	Hunan Yahua Seed Industry Research Institute
Hybrid rice	Zhong You 9918	Changsha Institute of Agricultural Sciences
Hybrid rice	Jin You 284	Hunan Yahua Seed Industry Research Institute
Hybrid rice	Xiang Fei You 8118	Hunan Keyulong Seed Industry Co., Ltd
Hybrid rice	Liang You 336	Hunan Jinjian Seed Industry Technology Co., Ltd
Hybrid rice	C Liang You 266	Hunan Institute of Nuclear Agronomy and Aerospace Breeding

Table 2. Examples of major crops other than rice that accumulate low Cd.

Type	Variety	Reference
Wheat	Arcola, G9265-AU	Zhao et al. (2024)
Maize	JHY809, JDY808, AD778, SN3H, SY13	Zhang et al. (2022)
Maize	Xianyu 335	Wang et al. (2022)

Barley	Beitalys, Shang 98-128	Fang et al. (2006)
Maize	L63	Zhang et al. (2021)

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Perspective

Knowledge from research articles of WG4 Cost Action members will be transferred to the applied sector using a database tool that will be freely available. This tool will be fulfill with main outcomes from breeding and agricultural management strategies to enhance nutritive value of crops in the current context of climate change while reducing the environmental pollution by agriculture and industrial sector by sharing best practices.