Keeping toxic cadmium out of the food chain

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The discovery of a natural variation in an ancient rice variety shows the way to reduce the harmful element cadmium in a key food without sacrificing yield and concentrations of other essential nutrients.

Cadmium (Cd) is a potential human carcinogen, and chronic low-level exposure to Cd has been linked to heart disease, cancers, kidney malfunction and decreased bone density. Small amounts of Cd in soil are taken up relatively efficiently by many crops, including rice, but it is taken up inadvertently by transporters that evolved to supply essential micronutrients. A further problem is that Cd is not toxic to plants in small quantities, and so is not readily detected in toxic symptoms or decreased yields. So, crops can grow and produce products that exceed limits set on Cd concentrations [1]. . Because of its strong uptake and health impacts at low concentrations, for many areas in countries around the world, Cd is perhaps the most important of the toxic elements within the food chain. The greatest exposures are from staple crops consumed in large quantities, such as wheat, potatoes and rice [2,3,4,5].

In a survey in a metal-mining county in Hunan province in China, 88% of the rice grain exceeded the permissible limit of 0.2 mg Cd kg dry weight; in that area, the calculated median dietary intake per month was 2.7 times higher than the US Food and Drug Administration and World Health Organization limit of 25 μg Cd kg body weight for the general population, and 4.6 times higher than the limit for children [6] (Fig.1). In other continents where data exist, for example Europe, mean total population Cd intake, mainly from food, excluding those living in highly contaminated areas, is close to or exceeds the tolerable weekly intake [3].

Writing in Nature Food, Yu and colleagues propose a new way to address this problem based on the discovery of a duplication of the *Oryza sativa* OsNRAMP5 gene in an ancient indica variety of rice called Pokkali [7]. The OsNRAMP5 uptake protein is known to transport both Cd and the essential elements magnesium (Mn) and iron (Fe) but intriguingly, the duplication results in more Cd being held in the roots. Yu and colleagues demonstrated that introgression of this naturally duplicated OsNRAMP5 allele into the elite japonica variety Koshihikari resulted in lower concentrations of Cd in rice and grain, without undesirable effects on yield and concentrations of other essential nutrients [7].

At first sight, this appears counterintuitive. How can doubling the expression of a transporter for Cd uptake from the soil decrease Cd concentrations in shoots and grain? The answer relates to various transporters in the plant and the exquisite compartmentation of the plant at a tissue and cellular level. The authors showed that doubling OsNRAMP5 expression increases Cd and Mn in the root [7]. However, the concentrations in the xylem sap (exported from the root to shoot) were massively decreased in the case of Cd, but increased for Mn. This is due to the gene OsHMA3 in root cells, which is responsible for sequestration of Cd in the vacuolar subcellular compartment [8]. Mn, however, is efficiently transported through the root cell and towards the shoot by OsMTP9, which transports only Mn and not Cd. The authors used elemental mapping with LA-ICP-MS (laser ablation inductively coupled plasma mass spectrometry) to clearly demonstrate that Cd is retained at the root exodermis and endodermis in their introgressed line, whereas Mn is not [7].

This leaves one question: why is Cd accumulated in the root and not exported to the rest of the plant via the xylem? The transporter responsible for Cd efflux from root cells towards the xylem is unknown [7]. The authors postulate that the extra Mn in the cell due to doubling OsNRAMP5 competes effectively with Cd at that transporter for efflux. The result is higher Cd in the call sap, and this presumably stimulates its detoxification by sequestration into the vacuole through expression of OsHMA3 [8]. Neither yield nor eating quality, nor essential micronutrient concentrations Mn, Fe and zinc (Zn), are affected by the background gene doubling in this popular rice variety [7]. This is a great step forwards compared to other attempts to decrease Cd in rice. For example, knocking out OsNRAMP5, OsHMA2 and OsZIP genes (the latter are required for essential Zn transport) [7,9] could result in lower rice yields – likely caused by, or certainly resulting in, lower uptake of essential micronutrients. Indeed, the same authors overexpressed OsHMA3 in indica rice and found that Cd concentrations decreased by 94–98% [8]). However, overexpression of OsHMA3 resulted in higher concentrations of the essential micronutrient Zn in the roots and lower concentrations in the shoots, which may not be beneficial for plant and human nutrition. The overexpression was also generated using a genetic modification approach.

The approach of Yu et al. may therefore be deemed more acceptable by the public as it harnesses natural variation and conventional breeding, and may provide a long-awaited practical solution to reduce Cd intake by breeding a low-Cd variety into a high-yielding variety. As the authors state, more development is needed to make available commercial varieties adapted to local environments. Testing the impact of the environment on a variety’s performance will also be important. For example, we know that when soil dries, less Cd exists in the form of insoluble cadmium sulfide (CdS) than in flooded soils. For Mn the opposite occurs, with more insoluble manganese dioxide (MnO2), which is less available under dry conditions. Due to climate change and the increasing shortage of water for irrigation, more rice needs to be grown under drier soil conditions, which tends to decrease the bioavailability of Mn but increase that of Cd. This may be another benefit of doubling OsNRAMP5. In addition, the work hopefully represents a step in reducing Cd in other crops, in which homologous genes and similar intricate homeostasis mechanisms occur.

Finally, it should be noted that this approach does not remediate the soil itself, as Cd remains largely in the roots and therefore the soil. It should not be used as any form of excuse not to control Cd emissions in the environment where it often ends up accumulating in the soil [5,7], from which it is slow and prohibitively expensive to remove.

Competing interests

The author declares no competing interests.

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