Reducing risks from rice

Professor Zueng-Sang Chen explains his research into developing different technologies to reduce the health risk from brown rice and vegetables grown in cadmium and arsenic contaminated sites

Could you summarise the context of your work?

My field of study is developing remediation methods for soils contaminated with heavy metals with the goal of producing safe agricultural products, especially rice and vegetables, for consumers. The key aims of the health risk assessment are to reduce the concentration of dissoluble cadmium and arsenic ions from the contaminated soils and also to reduce the uptake of cadmium and arsenic into the edible parts of rice and vegetables.

What initiated your interest in contaminated soils and how has your career developed to this point?

Prior to 1990 I worked as a pedologist, which required me to undertake a survey on soil management, sustainable land use and soil environmental quality. In 1984, this presented a good opportunity to join a survey and evaluation project on heavy metals pollution of Taiwan rural soils, supported by the Taiwan Environmental Protection Administration (EPA). Afterwards, I became chairman of a project which, among other things, aimed to help Taiwan EPA develop a 'Remediation Act' for soil and groundwater pollution.

In 2001, I led another project on the regulation (or pollution control level) of heavy metals in Taiwan's rural soils focused on basic soil characteristics and background concentration of heavy metals. More recently, in 2014, I became the leader of a project to revise the regulation of pollutants in soil and groundwater.

How have you assessed the impacts of contaminants of rice and vegetables on human health?

We collected information on the concentration distribution of 12 rice varieties and several types of vegetables grown in a range of contaminated soils. We also measured total intake of different rice varieties and vegetables by consumers. We then evaluated the total intake per week (TIPW) per person of cadmium, inorganic arsenic, total arsenic, copper, zinc, lead, chromium and nickel, and compared it with the critical value of TIPW announced by the World Health Organization (WHO).

To what extent are your current studies novel and how have you communicated your findings?

Our understanding of the bioavailable arsenic concentration of the Guandu Plain soil in northern Taiwan is novel. The arsenic is relatively insoluble here because the soils have high iron, aluminium and organic matter content, in an area with good water management practices. Some potential health risks still exist for farmers exposed in that area and we have subsequently promoted risk communication with the farmers to diminish this, encouraging them to wear long shirts, masks and reduce working time in the field.

We also found that the total arsenic concentration or inorganic arsenic levels in some varieties of brown rice grown in contaminated soils (>60 mg/kg) in southern Taiwan are still less than 0.3 mg/kg, which is near the background level. The major reason for this is the irrigation water pumped up from the groundwater, which contains a high concentration of ferrous iron. This combines with inorganic arsenic ion to form a non-soluble state which can't be taken up into brown rice. As a consequence of our health risk evaluation, policy makers have been informed that the rice is safe for consumption.

Have any of these findings been applied to date?

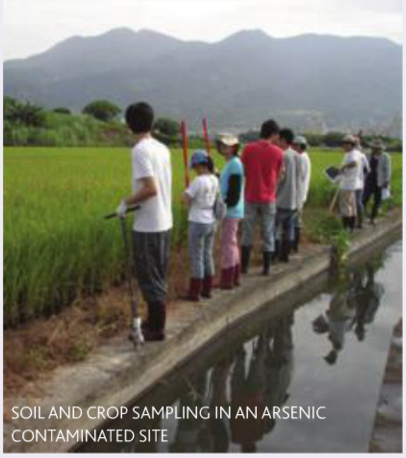
Taiwan EPA has decided the regulations around pollutants in soil and groundwater pollution sites should be revised. Instead of using one target value for each site, the issue is being tackled using a health risk-based approach. That means we can reduce the remediation goal based on the risk assessment, not the total concentration of pollutants. This has already been carried out in two cases in Taiwan; the arsenic-polluted sites of Guandu Plain of northern Taiwan and the rural soils of southern Taiwan affected by pumping up groundwater. This is a great step which we hope will be implemented in remediating arsenic contamination sites in the future.

How do you foresee this field of research developing in years to come?

The key challenge of cleaning up the contaminated sites over the last few decades was to select and create cost-effective and environmentally friendly technologies. Subsequently, we should use new, innovative technologies to assess and remediate contaminated sites, instead of relying on traditional, known technologies. We also need more communication with local communities and policy makers, as well as more international cooperation.

The arsenic antidote

Health issues arising from heavy metals in food supplies affect many Asian countries. Researchers at the National Taiwan University are exploring methods of soil remediation to reduce human consumption of carcinogenic metals



SOIL AND CROP SAMPLING IN AN ARSENIC CONTAMINATED SITE

RICE AND VEGETABLES are a staple food source in Asian countries, constituting 80 per cent of human food consumption and occupying vast tracts of arable land for their production. As a consequence of this mass dependence, ensuring these foods meet the criteria for safe human consumption is a primary concern for policy makers. Unfortunately, one of the consequences of East Asia's industrial boom is environmental contamination, particularly the release of toxic, heavy metals into the environment from industrial parties. Heavy metals such as arsenic and cadmium are easily taken up by vegetation via the root system and are redistributed throughout the plant where they can accumulate in substantial concentrations. While this in itself can damage crops and affect yield, secondary consumption by humans poses a far more significant risk.

Arsenic and cadmium are categorised as class one carcinogens by the International Agency for Cancer Research. Continued exposure to the metals via the food chain puts the consumer at a considerably elevated risk of developing cancer. Consequently, government schemes have attempted to cap the cadmium and arsenic concentrations permitted if land is to be used for agricultural purposes. These schemes, including one put in place by the Taiwanese Government, have been found to overestimate safe levels of arsenic and cadmium. This solution is not practical, as reducing arable land availability places increased pressure on an already stretched food production sector.

FIRST STEPS

Work led by Professor Zueng-Sang Chen and his team at the National Taiwan University is focused on risk assessment, soil remediation and phytoremediation to ensure the continued growth of safe foodstuffs, which is vital for consolidating food security. The first step to realising this goal is to assess the risk from common toxic metals including arsenic, cadmium, copper and zinc. Calculating and communicating the risk presented by each of these toxic elements is vital for forming a strategy to lessen exposure. This concept has been grown by the research team who have analysed the uptake of several dangerous metals by common varieties of rice. While experimental evidence from the Taiwan Agricultural Research Institute (TARI) found that most of the toxic metals did not show variation between rice varieties, the study of cadmium contaminated soils produced interesting results. The team from TARI and the University concluded that Indica rice varieties take up significantly higher concentrations of cadmium than other varieties, such as Japonica. Consequently, consumers of Indica rice are at a higher risk of poisoning from cadmium. The study also identified other factors that heighten the risk, including the pH of the soil and the total cadmium concentration within it.

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Once the risk from the pollutants has been elucidated, the next step is to develop methods to reduce the total concentration of harmful metals in the soil. The researchers have harvested information from rice paddy fields in the Guandu Plain in northern Taiwan to design optimal methods for remediating the soil. The Guandu Plain had a vast acreage of contaminated soils, with arsenic concentrations well above the safe levels suggested by Taiwanese Government policy.

Initial studies noted that there is a weak correlation between the amount of arsenic in the soil and the amount found in the crops. In fact, only 'bioavailable' arsenic is taken up by the plants. Bioavailable arsenic constitutes soluble arsenic which can be absorbed into the plant's xylem and hence, the higher the soluble arsenic in soil solution, the greater the affect on the plant. In addition, the three-year project, supported by the Ministry of Science and Technology of Taiwan, found that by following a series of steps, it was possible to reduce the bioavailable arsenic level in the soil to a safe background level of brown rice. The process involved draining the surface water of the paddy field for at least three weeks during the maximum tiller and flowering stages of rice production. This created aerobic conditions to reduce the solubility and concentration of arsenic in soil solution, especially in soils with high amounts of amorphous iron oxides and free iron oxides; this in turn affected the arsenic chemical forms of the compounds.

After the water management procedures were initiated, the team found that concentration of dimethyl arsenic (DMA) was reduced and total arsenic was, subsequently, less likely to be absorbed into the plant's vascular system. Levels of inorganic arsenic (III) were also recorded, as it is extremely hazardous to human health. While these values were increased, they were still within safe ranges. In addition, the rice plants found to have a large quantity of iron plaque along their roots had a reduced arsenic uptake into the rice grain in certain iron rich soils. The conclusions of the study highlighted the hazards of current methods of rice farming. Leaving fields flooded throughout the stages of rice production actively leads to arsenic accumulation in brown rice, while draining at certain stages before the flowering stage significantly reduces it.

A STEP FURTHER

With this progressive insight into arsenic remediation, the researchers have also investigated further techniques with the aim of deducing practical and affordable remediation strategies to tackle the risk from the other harmful toxins. This aspiration has prompted the researchers to plant the seed for new, green, low cost strategies which harness the power of plants to help clean up the soil, as Chen explains: "We selected two plants with cadmium super accumulating capabilities; impatiens and the French marigold. These plants show very high accumulation of cadmium in the upper part of plant, ranging 280 to 1,200 mg/kg. Their removal capacity is about 300 to 1,000 times greater than that of general flowering species".

The team discovered that by planting these species in the pollutant rich soil they were able to reduce the metal concentrations to a safe level over several years in multiple metals-contaminated sites of central Taiwan. Copper was found to be the quickest to clean up, with the phytoremediation being complete after four years, while zinc and chromium were more time consuming, taking an estimated 17 and 31 years respectively. However, the real selling point of

> Calculating and communicating the risk presented by each of these toxic elements is vital for forming a strategy to lessen exposure

this simple yet effective technology is the low cost and high economic benefit for farmers, meaning it is likely to be a popular solution among the agricultural community.

REDEVELOPMENT CHALLENGES

With Chen's current research already providing a positive outlook for farms in polluted areas, other more advanced technologies hold promise that total prevention and remediation may be possible in the future. The success of this important project supported from Taiwan Environmental Protection Administration (EPA) relies not only on developing more innovative mechanical technologies, but also in integrating them with new biotechnologies.

In addition to already refined techniques, such as soil management and amendments, the next step is to get to the root of the problem by redeveloping the plants themselves. Genetic modification of edible rice and plant varieties to combine them with plants that display low cadmium and arsenic uptake may provide the solution to end the contamination of the food supply for good. Needless to say, the work undertaken by the National Taiwan University is a vital ingredient in ensuring millions of people are getting safe food on the table.

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INTELLIGENCE

REMEDIATION OF SOIL AND GROUNDWATER POLLUTION IN THE ASIA-PACIFIC REGION

OBJECTIVES

- To develop methods for the decontamination of heavy metals, such as dissoluble cadmium and arsenic ions, from soils in order to yield safe agricultural products for consumers – particularly rice and vegetables
- To develop good relationships between heavy metals uptake of brown rice or vegetables and bioavailable or extractable contents of metals in the contaminated soil
- To find some plants have very high accumulation of heavy metals from the contaminated soils

KEY COLLABORATORS

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