Breeding for metal tolerance in food crops

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Carcinogenic and mutagenic metal compounds are ubiquitous in distribution and their concentration in soils is on the increase. They are either transformed or transmitted naturally or anthropogenically. Modern agricultural practices using fertilizers and pesticides have accelerated the increase of metal burden in the soils. This has invariably led to higher concentration of metals in the food crops. Therefore, food scientists need to restrict the residual contents of toxic metals in foods. This could perhaps be overcome by emphasizing research programmes for screening of vast germplasm and to select genotypes for low uptake of metals from soils. Since different cultivars respond to varying amounts of metal uptake, based on their genetic make up, this could perhaps serve as an excellent tool for control of metal concentration in food crops.

OVER the decades agricultural research was primarily directed towards increasing crop productivity. This was achieved with the application of advanced breeding programme and introduction of modern agricultural practices involving substantial inputs of a variety of agrochemicals such as fertilizer and pesticides. These agro-chemicals contain varying amounts of heavy metals. Phosphatic fertilizer, particularly rock phosphates, significantly increases Cd in soils. Because of its geochemical origin, rock phosphates are contaminated to great extent by cadmium[1]. Contents vary depending on origin, from less than 1 ppm to extreme values of 90 mg/cd/kg (Table 1). During chemical processing this cadmium is transformed more or less completely into phosphate fertilizer. Because of its toxicity, fears have been expressed about cadmium transfer to humans via phosphate fertilization applied in the soils.

Studies conducted in North Carolina revealed fertilizers applied over 100 years have contributed appreciably to increased amounts of Cd, Cr, Ni and Zn metals in soils[2]. At Rothamsted in UK, the average annual increase of Cd in wheat-grown soils has been estimated as 4.5 g ha^{-1} since 1990s with further accelerated rate of increase in recent times[3].

Anthropogenic sources of metal pollution

Table 2 shows anthropogenical sources of metals pollution which include fossil fuel combustion and vehicle exhaust, mining operations, smelting as well as other industrial effluents which greatly contaminate soils[4,5].

Combustion of coal for thermal power generation is a major contributor of heavy metals. Flyash from thermal power station, through aerial deposition, adds significant amount of toxic metals like cadmium, lead, vanadium and selenium[5].

Similarly automobile exhaust also contributes significantly to metal burden, like lead, especially on the road-side soils resulting in lead contamination in both soils and vegetation[6].

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Metal uptake in food crops

Thus, metal stress problems of variable types occur virtually in all areas of crop production. Since food forms a major non-occupational source for the exposure of man to toxic metals, especially cadmium[7], concern is expressed over metal concentration in food crops. The uptake of metals from soils is high in leafy vegetables, like spinach and cabbage, when grown in sewage sludge containing elevated concentration of toxic metals[8] (Tables 3 *a* and *b*).

Table 1 *a*. Some reported cadmium concentrations in fertilizers[1]

	Cadmium (ppm)
Rock phosphate	31–90
US fertilizers	0–30

Table 1 *b*. Metal content of some soils affected by mining (ppm) (after Davis[16])

Lead	Range	Means
	18–3422	395
Zinc	44–1905	232
Copper	3–523	56
Cadmium	0.4–2.3	1.2
Mercury	0.01–1.78	0.25

Among cereal crops, cadmium uptake from soil and water by rice crop is generally high and therefore a major source of cadmium intake is via rice in rice-eating countries[9]. The daily Cd intake of 50% in Indonesia and 40–60% in Japan comes alone from rice[10,11]. Thus, rice along with other cereal serves as the best indicator for environmental monitoring of Cd, especially in rice-eating countries[12]. Hence, apart from monitoring, strategies should be developed to control their concentration in food crops. Since the uptake of these metals varies among different genotypes, breeding of cultivars and their subsequent selection for tolerance to toxic metals is a promising alternative for overcoming metal toxicity. Crop tolerance to aluminum and manganese has been investigated over many years and the genetic variability has been observed in many cultivable species[13]. Tolerance is metal specific, suggesting the operation of different genes for different toxic metals. However, genotypes tolerance to single or multiple toxic metals have been established[14]. *Agrostis tenuis* ecotypes were found to be tolerant to both copper and nickel. On the other hand, some plant genotypes showed negative tolerance to excess of aluminum and manganese. Atlas '66', a wheat tolerant to aluminum, is sensitive to manganese. However, the potential for genetic recombination resulting in multiple tolerances is quite possible[15].

Table 2. Lead, zinc and cadmium content of soils and radishes as affected by aerial contamination (Langerwerff[4])

Metal	Soil content (ppm)	Roots	Tops
Lead	300	21	26
Cadmium	0.1 and 0.6	1.0 and 1.8	31/45
Zinc	10	81	141
	60	121	248

Table 3 *a*. Heavy metal concentrations in sludge (ppm) (Srikanth and Reddy[8])

Metal	No. of samples	Range	Arithmetic mean
Lead	20	80.00–280.35	183.50
Cadmium	20	12.50–35.50	22.00
Chromium	20	42.00–143.25	83.20

Table 3 *b*. Heavy metal concentration in different food crops grown in sewage sludge (ppm) (Srikanth and Reddy)[8]

Food crops	No. of samples	Range	Arithmetic mean
Lead			
Spinach leaf	20	5.50–22.58	14.94
Spinach root	20	5.50–22.58	16.10
Amaranthus leaf	20	7.50–14.50	12.20
Amaranthus root	20	3.00–68.20	38.57
Cabbage leaf (inner leaves)	10	5.50–10.14	7.52
Cabbage root	10	9.00–15.58	12.64
Cadmium			
Spinach leaf	20	0.90–9.67	6.40
Spinach root	20	3.20–14.70	8.20
Amaranthus leaf	20	1.50–2.70	1.10
Amaranthus root	20	2.50–14.10	8.44
Cabbage leaf (inner leaves)	10	1.30–4.75	2.88
Cabbage root	10	1.30–4.75	2.88
Chromium			
Spinach leaf	20	5.50–22.58	13.48
Spinach root	20	6.00–23.61	15.00
Amaranthus leaf	20	7.50–14.50	10.12
Amaranthus root	20	3.00–68.20	29.22
Cabbage leaf (inner leaves)	10	4.00–9.00	6.21
Cabbage root	10	8.00–13.58	10.55

Breeding for metal tolerance

Until recently no crop variety has been released as a product of selection programme consciously designed for adaptation of metal stress. Existing metal-tolerant varieties have been developed by breeders in environments where natural selection pressure for toxic or deficient metal(s) were operating. This has taken place with the breeders being unaware of the selection pressure operating either within the soil or due to naturally-developed tolerance. The highly aluminum tolerant wheat varieties developed on acid soils in Brazil is a good illustration of this process[12].

Agronomically important characters, including responses to metal stress are more often controlled by large number of genes (polygenes) with moderate effect. Therefore, advanced breeding programmes have to be directed for developing cultivars adapted to different kind of metal stresses in important food crops. Newly identified genetic sources of metal tolerance coupled with rapid screening techniques and greater understanding of the genetics and physiology of metal stress assure faster progress in breeding programmes.

Biotechnological approach

In vitro techniques are useful in the study of genetics and metal tolerance. These methods may be suitable for the identification of plants possessing tolerant genes at the cellular level and might help to identify and locate metal tolerance genes in plant genomes using molecular techniques.

Genetic differences for metal tolerance occur due to differences between genotypes within crop species. The differential response of genotype within crop species to metal stress is of considerable interest. Because of this, variability can also be used in the development of metal-tolerant cultivators.

Conclusions

Concerted efforts need to be launched to control the metal residues in food crops, especially with the advent of industrialization and environmental position. Apart from regular monitoring of metals in soils and crops, stress should be laid to develop metal-tolerant plants. This can be achieved by using modern techniques of breeding and molecular biology.

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