Genotypic variation in micronutrient and cadmium concentrations in grains of 35 upland rice cultivars

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Abstract
Rice is the primary food for half of the world population and in Brazil it is the most consumed cereal. Plant breeders have selected rice cultivars for high micronutrient density traits, but there is a need to include other elements that can affect micronutrient bioavailability, such as cadmium (Cd). The study was conducted with the purpose of evaluating the relationships among Cd, zinc (Zn), iron (Fe), and selenium (Se) concentrations in grains of upland rice cultivars. Thirty-five upland rice cultivars were grown to maturity in a pot soil experiment under greenhouse conditions. Cadmium and micronutrient concentrations in grains ranged widely, but showed a close relation with grain yield. While the grain-Cd concentration increased with the increase of grain yield, an opposite relationship was found for grain micronutrient concentrations, which declined with increased grain yield. It appears that rice plants use different mechanisms to regulate the accumulation of toxic and essential heavy metals into grains.

Key Words
Grain-Cd concentration, heavy metals, translocation, uptake, soil pollution, human health.

Introduction
Micronutrient malnutrition is today the major human health concern around the world, especially in developing countries. According to the World Health Organization more than 2 billion people may be anemic as a consequence of Fe deficiency (Allen *et al.* 2006). It has been estimated that one fifth of the population ingests inadequate amounts of zinc (Hotz and Brown 2004) and Combs Jr (2001) has estimated that between 0.5 and 1.0 billion people could be deficient in selenium. Development of crop plants with high Fe, Zn and Se in their edible parts will benefit from a better understanding of processes related to micronutrient acquisition (Welch and Graham, 2004). Factors related to environment, adaptation, and selection can increase or decrease the absorption of a given element in favor of another. However, one given gene or group of genes may control the absorption of a single or more elements (McLaughlin *et al.* 1999) and anti-nutritional factors such as Cd can increase in edible parts. Little is known about the efficiency of acquisition and utilization of micronutrients and their relationships to anti-nutritional factors. The objective of this study was to evaluate the relationship between micronutrient and cadmium accumulation in upland rice grains of 35 cultivars.

Methods
A pot experiment was carried out in a greenhouse at the Center for Nuclear Energy in Agriculture (CENA), University of Sao Paulo (USP), Piracicaba, SP, Brazil. Pots with 3 dm^3 of an acid Oxisol received lime and fertilizers as recommended for upland rice and after one month seeds were sown. Micronutrients and Cd were supplied together with fertilizers at rates (mg/dm^3): Se - 0.1, Zn - 3.0 and Cd - 1.0. Thirty-five upland rice cultivars were selected according to the following characteristics: old and new cultivars, duration of life cycle, high and low content of minerals in grains, yield, type and color of grain (red, black or white). Three plants per pot with thee replicates were used and after maturation, the plants were harvested. Samples of brown rice grains were digested in $HNO_3 + H_2O_2$ and analyzed by ICP-MS. A reference material (NIES N^o 10, Rice Flour-Unpolished) was used to assure the quality of analysis results.

Results
Large differences were observed in both grain yield and concentrations of Cd, Fe, Zn and Se in rice grains (Table 1). There was a significant direct relationship between grain yield and grain-Cd concentration. In contrast, an opposite relationship was observed among the grain yield and grain micronutrient concentration (Table 1).

Table 1. Grain yield, concentration of Cd and micronutrients and their relationship in grains of 35 upland rice cultivars.

Cultivars[(1)]	Grain yield	Grain concentration			
	g/pot	Cd	Fe	Zn	Se
		mg/kg			µg/kg
IAC 4440	24.0	1.76	20.5	24.4	57
PB 11	13.7	1.54	15.8	25.2	35
PB 05	21.8	1.53	15.8	36.0	17
BRSMG Relâmpago	11.5	1.23	19.3	32.9	16
BRSMG Caravera	15.9	1.21	21.3	25.4	15
BRSMG Curinga	17.3	1.04	31.3	36.6	74
Pérola	1.5	1.03	25.0	34.2	64
Bonança	13.0	0.95	15.9	37.2	42
Jaguari	1.7	0.93	25.1	44.7	48
Primavera	5.5	0.79	21.4	45.1	53
IAC 201	9.6	0.74	29.7	33.5	61
IAC 600	1.6	0.67	23.5	39.0	47
Gurani	11.9	0.65	16.9	37.7	56
Caiapó	9.3	0.61	18.3	43.2	63
Bico ganga	8.4	0.59	25.2	43.8	27
IAC 435	1.8	0.55	23.0	25.7	63
BRS Talento	12.9	0.53	31.0	34.8	55
Canastra	7.1	0.53	25.7	43.3	73
PB 01	16.0	0.53	15.2	30.0	17
Arroz preto	9.1	0.50	27.5	42.3	47
IAC 165	7.0	0.49	25.6	39.5	58
BRSMG Conai	13.2	0.48	15.9	34.1	40
Carajás	12.3	0.48	14.5	32.1	56
IAC 47	6.6	0.46	23.3	41.1	44
IAC 202	11.3	0.42	21.1	34.3	63
Pratão	1.7	0.38	22.6	41.6	39
Beira campo	13.4	0.36	19.2	40.4	36
Maravilha	6.4	0.32	17.1	37.6	42
IAC 25	9.2	0.32	21.7	37.5	48
Batatais	1.0	0.31	26.0	29.6	49
Dourado precoce	2.6	0.30	31.3	44.5	85
IAC 4	2.4	0.29	25.1	39.3	122
Cateto	2.4	0.28	20.2	40.6	40
IAC 1246	8.2	0.19	29.1	42.6	115
Cateto seda	6.9	0.17	31.4	39.5	71
DMS, Tukey 5%	*7.9*	0.13	5.2	6.5	15
	Pearson's correlation coefficient				
Grain-Cd concentration	0.56***	-	-	-	-
Grain-Fe concentration	-0.34***	-0.28***	-	-	-
Grain-Zn concentration	-0.40***	-0.47***	0.31***	-	-
Grain-Se concentration	-0.31***	-0.39***	0.52***	0.28***	-

[(1)]Following rates of the elements were applied (mg/dm^3): Se - 0.1, Zn - 3.0 and Cd - 1.0; ***significant at 1% level.

In addition, significant negative correlations were found between the concentrations of Cd and micronutrients in rice grains. However, just positive relationships were observed among the concentration of micronutrients in upland rice grains (Table 1). High grain yields may lead to a reduction in micronutrient grain concentration as suggested by recent studies (Garvin *et al.* 2006; Murphy *et al.* 2008). Thus, it was expected that grain-Cd concentration would also be low in the cultivars that showed high yields, but actually an opposite result was found. So it seems that rice plants may use different mechanisms to regulate the accumulation of toxic and essential elements into the grains, as suggest by Kubota *et al.* (1992).

Conclusion

Cadmium and micronutrient accumulation in upland rice grains seem to be differentially controlled as there was an opposite relationship among their concentration. Breeding programs can easily screen rice plants for both low cadmium concentration and high micronutrients density traits.

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