Zinc uptake and allocation in rice

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Abstract

Rice is a major staple food and also a major zinc (Zn) source for people with diets predominantly based on rice. However, Zn density (mg Zn kg^{-1} rice) in polished rice is low and Zn deficiency is common in people depending on rice-based diets. We therefore explored which internal crop processes limit allocation of Zn to the edible portions of rice grains. Rice plants were subjected to a range of Zn supply rates in a solution culture experiment and in a field experiment. Under sufficient Zn supply in the solution culture experiment, accumulation of Zn in the grains was virtually identical to Zn uptake after flowering, while leaves retained all Zn. In the field experiment, fertilisation only had a minor positive effect on grain Zn density. Under field conditions Zn uptake during grain filling was only about 45% of total grain Zn accumulation, while reduction in leaf Zn was equivalent to about 15−20% of grain Zn accumulation, indicating a potential role for Zn remobilisation. The solution experiment confirmed that the potential to increase grain Zn density is limited, in contrast to Zn density in vegetative plant parts. Zn appeared to be transported freely between roots and shoot, while transport between stem and rachis and between bran and endosperm was limiting when overall Zn density in the plant increased. The major bottleneck occurred between bran and endosperm.

Media summary

By simply increasing Zn supply to the rice plant, grain Zn density could not reach the level that would alleviate human Zn malnutrition; breeding and agronomy are to work hand-in-hand to enhance Zn accumulation in rice grains under field conditions.

Key words

Zn, grain Zn density, rice

Introduction

Zinc (Zn) deficiency affects over 30% of the world population (Welch et al., 2005). Zn deficiency is especially prevalent among resource-poor women and children. Rice is the world's most important staple crop, providing food for over half of the world's population, and rice grains are therefore an important dietary source of zinc for many resource-poor families globally. However, Zn density (mg Zn kg^{-1} grain dry matter) in polished rice is generally less than 25 mg kg^{-1} (Heinemann, 2005; Ma, 2005), which is too low to meet human Zn requirements (40−80 mg kg^{-1}, Jiang et al., 2008b). We therefore explored which internal crop processes limit allocation of Zn to the edible portions of rice grains.

Material and methods

Field experiment

The field experiment was carried out in Mengcheng, Anhui province, China (33°55' N, 116°15' E) in 2004. The soil at the experimental site is a Shajiang black soil (vertisol; Anonymous, 1998) with pH 6.8. DTPA-extractable Zn was 0.30–0.40 mg kg^{-1} soil. Aerobic rice cvs Handao502 (a newly developed cultivar) and Baxiludao were grown under two Zn levels: without Zn (−Zn) and with Zn (+Zn, 20 kg Zn ha^{-1}). Other field management details can be found in Jiang et al. (2008a).

Solution culture

In a second experiment, plants of cultivars Handao502 and Baxiludao were grown on half-strength Hoagland solution (pH 5.6 ± 0.1) with either sufficient or surplus Zn added. Details on Zn application to the solution medium can be found in Jiang et al. (2008b). Plants were grown in a glasshouse set to maintain a day/night temperature of 28 °C/21 °C at the Chinese Academy of Agricultural Sciences, Beijing, during the summer season of 2005.

Sampling and chemical analysis in both experiments

In both experiments, plants were harvested at flowering and at physiological maturity. All sampled plant materials were dried at 75 °C for 48 hours, ground in a stainless steel mill and digested in a bi-acid mixture (HNO3: HClO4 = 4:1). Zn was determined by atomic absorption spectroscopy (SPECTRAA−55; Varian Australia, Mulgrave, Australia).

Brown rice samples from a selection of treatments of the solution experiment were polished, the bran and polished rice were collected separately, digested and analysed using the ICP-AES of the Waite Analytical Services, Adelaide, Australia.

Results

Under field conditions (both with and without Zn supply), about 45% of total grain Zn accumulation originated from Zn uptake during grain filling, and the reduction in Zn in leaves was equivalent to about 15−20% of total grain Zn, indicating a potential role for Zn remobilisation (Table 1). When given sufficient or surplus Zn in the solution culture experiment, grain Zn content was virtually identical to Zn uptake after flowering, while stems and sheaths and even leaves (despite a small reduction under Zn-sufficient conditions) retained more or less all Zn. Under field conditions, Zn addition (20 kg ha^{-1}) only increased grain Zn density (mg Zn kg^{-1} dry matter of rice) by 11−13% compared to that without Zn supply (Figure 1).

In the solution culture experiment, with surplus Zn supply, Zn density in all individual organs increased (Table 1). However, the increase in Zn density in stems was much larger than in grains. Under surplus Zn conditions, there were strong gradients in Zn density from stem to rachis, and from bran to endosperm, suggesting transport limitations between these organs

(Table 2).

Table 1. Zn uptake and change in Zn content in leaves, sheaths, stems and whole grain (brown rice) between flowering and maturity.

Table 1. Zn uptake and the change of Zn content in leaves, sheaths, stems and whole grain (brown rice) between flowering and maturity.

		Zn content (μg m^{-2})				
Field		Total plant Zn uptake	Leaf	Sheath	Stem	Grain
−Zn	Flowering	8500	2350	2000	1600	0
	Maturity	9800	1900	1370	800	2900
	Change	+1300	−450	−630	−800	+2900
+Zn	Flowering	9500	2800	2200	1700	0
	Maturity	10900	2050	1320	1000	3600
	Change	+1400	−750	−880	−700	+3600
Solution culture		Zn content (μg $plant^{-1}$)				
Sufficient	Flowering	90.0	33.0	26.0	8.00	0
	Maturity	137.0	25.0	31.0	11.0	27.0
	Change	+47.0	−8.00	+5.0	+3.0	+27.0
Surplus	Flowering	547.0	83.0	189.0	150.0	0
	Maturity	892.0	110.0	234.0	317.0	65.0
	Change	+345.0	+27. 0	+45.0	+167.0	+65.0

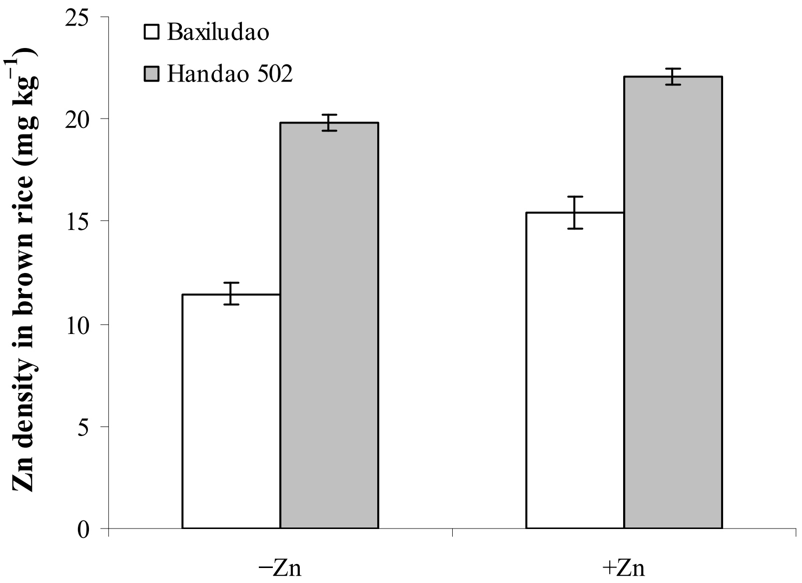

Figure 1. Effects of Zn application in the field experiment on Zn mass concentration in brown rice (means ± SD). Zn application treatments include without Zn (−Zn), and with 20 kg ha^{-1} (+Zn).

Table 2. Zn density in different organs in the solution culture experiment.

	Zn density (mg kg^{-1})	
	Sufficient Zn supply	Surplus Zn supply
Grain (brown rice)	20	45
Endosperm	20	30
Bran	60	100
Glumes	25	60
Rachis	25	120
Leaf blades	25	50
Stem	25	300
Root	25−60	200
Sheath	25	120

Conclusions

Under field conditions, there is some scope for increasing Zn uptake by fertilisation, thereby slightly increasing grain Zn density. However, the potential to increase grain Zn density was limited, in contrast to what can be achieved in vegetative plant parts with surplus Zn supply. Zn appears to be transported freely between roots and shoot, but major barriers seem to exist between stem and rachis, and between bran and endosperm. While fertilisation, especially after flowering, could help in soils that do not provide much zinc, from a human nutritional perspective , the genetic potential to accumulate zinc in rice grains should be increased.

References

Anonymous 1998. World Reference Base for Soil Resources. World Soil Resources Report 84. ISSS-ISRIC-FAO, FAO, Rome, Italy, 88 pp.

Heinemann RJB, Fagundes PL, Pinto EA, Penteado MVC, Lanfer-Marquez, UM. 2005. Comparative study of nutrient composition of commercial brown, parboiled and milled rice from Brazil. J Food Compos Anal. 18: 287-296.

Jiang W, Struik PC, Zhao M, Van Keulen H, Fan TQ, Stomph TJ. 2008a. Indices to screen for grain yield and grain-zinc mass concentrations in aerobic rice at different soil-Zn levels. NJAS − Wageningen Journal of Life Sciences. 55 (2) (in press)

Jiang W, Struik PC, Van Keulen H, Zhao M, Jin LN, Stomph TJ. 2008b. Does increased Zn uptake enhance grain Zn mass concentration in rice? Ann Appl Biol. (in press)

Ma GS, Jin Y, Piao JH, Kok F, Bonnema G, Jacobsen E. 2005. Phytate, calcium, iron, and zinc contents and their molar ratios in foods commonly consumed in China. J Agric Food Chem. 53: 10285 -10290.

Welch RM, House WA, Ortiz-Monasterio I, Cheng Z. 2005. Potential for improving bioavailable zinc in wheat grain (Triticum species) through plant breeding. J Agr Food Chem. 53: 2176-2180.