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Distribution of iron and zinc in plant and grain of different rice genotypes grown under aerobic and wetland conditions

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ABSTRACT

This paper examined the distribution of Fe and Zn in the plant and seed of different rice genotypes in different growing conditions. The Fe and Zn concentrations were determined in different plant tissues during the growth stages of 3 genotypes with high Fe and Zn check genotypes, and in different grain tissues of 15 genotypes grown in aerobic and wetland conditions. Iron and Zn were distributed differently in tissues of the rice plant, with the harvest index (panicle nutrient content as the % of the total above ground nutrients) at 3–4% for Fe and 54–74% for Zn. The concentrations of both Fe and Zn of the endosperm increased with the increasing proportion of the grain nutrient content allocated to the endosperm, but declined when the allocation to the bran fraction increased. The Fe concentrations of the de-husked caryopsis of rice grown in the aerobic soil and the Fe concentration of the de-husked caryopsis of rice grown in the wetland soil were closely related, but not in the endosperm Fe, while the grain Zn concentrations in the aerobic soil were found to correlate with the Zn concentrations in the wetland soil for both the de-husked caryopsis and the endosperm.

1. Introduction

Rice, the staple to most people in Asia, is especially low in grain Fe and Zn. It has been reported by the International Rice Research Institute (IRRI) that the yield from the largest rice germplasm averaged only 25.4 mg Zn kg^{-1} and 12.1 mg Fe kg^{-1} for brown rice, compared with an average of 35.0 mg Zn $kg^{-1}$and 37.2 mg Fe kg^{-1} for wheat germplasm, as reported by the International Maize and Wheat Improvement Center (Graham et al., 1999). The preference for white rice, from which the Fe and Zn rich bran fraction (which includes pericarp, tegumen, aleurone layer, and embryo; Fig. 1) is removed, further exacerbates the deficiency of these nutrients among rice eaters. It is not surprising that large sectors of the population in South and Southeast Asia are afflicted by Fe and Zn deficiency (Hotz and Brown, 2004). Biofortification, raising the concentration of the nutrients in the grain during the growing of the rice crop, has been suggested as one of the most effective ways to overcome the problem (Nestel et al., 2006). This may be done genetically, by breeding for genotypes that accumulate more Fe and Zn in the grain, or by crop management (Cakmak, 2008). However, in the case of rice, it is not known how Fe and Zn concentrations in the grain of different rice genotypes are affected when the rice is grown in waterlogged soil and when the rice is grown in well-drained soil, the two main soil–water management methods for the rice crop.

Iron toxicity and zinc deficiency are the two most common micronutrient disorders in rice production worldwide (Becker and Asch, 2005). The two metals respond differently to soil–water conditions when it comes to becoming available to the rice plant. Chemical reduction which follows oxygen depletion of waterlogged soil causes the concentration of Fe in the soil solution to rise, while that of Zn to decline (Ponnamperuma, 1972). The extent

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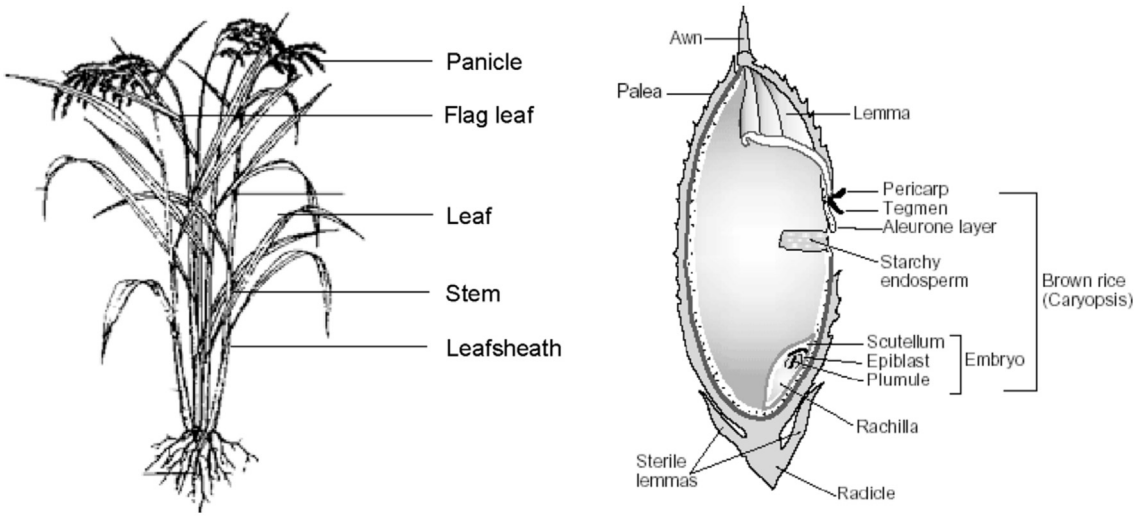

Fig. 1. A Diagram of rice plant (left) and seed (right), adapted from Matsuo and Hishikawa (1993).

of the rise and fall of the nutrients available to be taken up by rice roots varies with the chemical characteristics of the soil and the duration of submergence. Generally, the Fe in the soil solution increases to be in the range of 100–300 mg Fe L^{-1} in the first weeks of submergence, and then levels off to be in the range of 40–120 mg Fe L^{-1} as the rice approaches maturity (Sparks, 2003). In contrast, the rice plant growing in submerged soil has access to only 0.2–0.3 mg Zn L^{-1} in the soil solution for most of its life (Wissuwa et al., 2006). This basic difference in external availability of the two nutrients is reflected in their concentration in the plant of the field-grown rice, but not in the differential partitioning of the nutrients into the panicle. A dry season crop grown under wetland conditions at the International Rice Research Institute in the Philippines of IR8, one of Asia's first high yielding, semi-dwarf varieties, contained 470 mg Fe kg^{-1} in the straw which was more than four times that in the panicle, while Zn was more evenly distributed, with 24 mg Zn kg^{-1} in the straw and 22 mg Zn kg^{-1} in the panicle (Yoshida, 1981). Further variation was added to by genotypic differences, with IR8 allocating 46% of its above-ground Zn to the panicles, but the allocation to panicles in Peta, a traditional variety, was only 28%. Finally, there are variations in the concentration of Fe and Zn in the different tissues of the cereal caryopsis. A previous study of barley grain by using high definition synchrotron fluorescence showed large gradients in the distribution of Fe and Zn within and between different tissues, especially in the embryo and the scutellum regions (Lombi et al., 2011). In rice, the three genotypes with comparable ranges of Fe and Zn in their whole grain were shown to exhibit similar pattern of variation in concentration of the nutrients in the different grain tissues (Hansen et al., 2009). The lowest concentrations of both Fe and Zn were in the endosperm and the highest in the embryo, and the concentration of Fe was much lower than that of Zn in all the grain tissues. The technique of synchrotron X-ray fluorescence microscopy and high resolution secondary ion mass spectrometry further investigated the rice seed, and it was found that most Fe was localized with P in the aleurone layers, but small amounts were present in the endosperm which could be bound with nicotianamine and/or deoxymugineic acid (Kyriacou et al., 2014). This paper reports on the partitioning of Fe and Zn into the rice panicle and the variation of Fe and Zn distribution in the whole plant parts and in different grain tissues of different rice genotypes grown in both aerobic and wetland conditions.

2. Material and methods

2.1. Experiment 1

Three Thai rice genotypes (KPK, RD7, and KDML105) known to differ in the concentration of Fe and Zn in their de-husked caryopsis, and IR68144-2B-2-2-3 (referred to as IR68144), a standard genotype high in both Fe and Zn (Table 1), were grown in wetland conditions. One-week-old seedlings of the rice were transplanted into plastic pots (30 cm diameter, 30 cm depth) containing San Sai series soil (a sandy loam Typic Tropaqualf) at 6 plants pot^{-1}. Basal fertilizer was applied at the rate of 219 kg N, 120 kg P, and 327 kg K ha^{-1}. The soil in the pots were kept submerged under 5–10 cm of water throughout. The experiment was conducted in four independent replications, with three sets of pots for each harvest at heading, 10 days after anthesis (10 DAA) and maturity. At each harvest, the plants were separated into leaves, stem + leaf sheath, and panicles. At 10 DAA and maturity, the panicles were further separated into peduncle + rachis and spikelets, and at maturity, the seeds were separated into husk and de-husked caryopsis (Matsuo and Hishikawa, 1993) (Fig. 1). All the parts of the plant and the grain were surface washed with filtered water and deionized water. To determine the Fe and the Zn concentrations, subsamples of all the plant parts and seeds were oven dried at 70 °C for 72 h. The samples were dry ashed in a muffle furnace at 535 °C for 8 h, and the ash dissolved in 1:1 HCl. The concentrations of the Fe and the Zn were determined with an atomic absorption spectrophotometer. Soybean leaves were used as the certified reference material in each batch during the analysis.

2.2. Experiment 2

Fifteen Thai rice genotypes and two standard checks (IR68144 as in experiment 1 and high Fe, moderately high Zn Milagrosa) were grown in the field on Sansai series soil under wetland conditions at Chiang Mai University (18 °47′ N, 98 °57′ E) (Table 1) during the wet season, the main rice season in Thailand. Four-week-old seedlings of each genotype were transplanted into 3 × 4 m plots at 0.25 × 0.25 m spacing, in four replications. The field was kept flooded under 0.1–0.2 m of water until maturity. At 4 weeks after transplanting, 25 kg N and 14 kg P ha^{-1} were applied, followed by 63 kg N ha^{-1} 2 weeks later. The 15 Thai genotypes were also grown