Role of node in controlling traffic of cadmium, zinc and manganese toward rice grains

Chronic intake of cadmium (Cd) causes human health problems, such as renal dysfunction. Approximately half of Cd intake is attributed to rice consumption for typical Japanese. To reduce health risk caused by Cd intake, it is effective to develop a strategy to reduce Cd concentration in rice grains. For this purpose, it is necessary to understand the mechanism governing the transport of Cd to rice grains.

In rice plants, elements absorbed from the roots through the transpiration stream are redirected in the nodes, where vascular bundles linked with the roots, leaves, and panicles are interconnected (Fig. 1) [1]. Vascular bundles toward the flag leaf that become enlarged and elliptical when they reach the nodes are named enlarged vascular bundles (EVBs). The xylem parenchyma between the EVBs and diffuse vascular bundles (DVBs) serves as a bridge for the horizontal intervascular transfer of metals and is referred to as the parenchyma cell bridge (PCB). Metals transferred to the DVBs move toward the panicles (Chonan, 1993). The intervascular transfer of metals in the nodes is an important pathway for the redirection of metals from the xylem through the transpiration stream to the panicles. In this complex pathway that redirects elements from the roots to the flag leaf or panicles, toxic and essential elements are differentiated.

Metals accumulate in a particular part of a tissue when they are left behind by the flow because of the lack of a mechanism for transporting them into the adjacent cells. In addition to poor transport, storage and sequestration processes also cause metal accumulation. In this study, we compared the distribution of Cd around the vascular bundles in a rice node and those of zinc (Zn) and manganese (Mn), in order to determine where these elements were differentiated [2].

A rice plant (*Oryza sativa* cv. Koshihikari) was grown in a greenhouse and one week after heading, a node beneath a panicle was sampled and immediately frozen in hexane cooled by dry ice. 50-μm-thick cross sections were prepared by using a cryomicrotome (CM1850, Leica, Wetzlar, Germany) and then freeze-dried. By using a synchrotron micro-X-ray fluorescence spectrometer equipped with a recently developed mirror system that allows higher-brilliance microfocusing at beamline **BL37XU** [3], Cd, Zn, and Mn were detected simultaneously to determine the tissues in which they were accumulated in the node cross sections. The distribution of sulfur (S) was determined with an electron probe microanalyzer (EPMA; JXA-8500F, JEOL, Tokyo). Cd *K*-edge microfocused X-ray absorption near-edge structures (μ-XANES) were obtained at the Cd-accumulated points in the EVB.

Different distribution patterns of Cd, Zn and Mn in node I were observed, as shown in Fig. 2. Cd and S were accumulated in the xylem of the EVB, whereas Zn was localized in the PCB between the EVB and the DVB. Mn was localized around the protoxylem of the EVB. The Cd:Zn ratio was higher in the EVB and DVB, indicating that Cd flow was slower than Zn flow in these vascular bundles. The XANES analyses indicated that Cd was coordinated by S, probably in a form bound to a S-containing ligand.

Figure 3 illustrates the transport pathway of

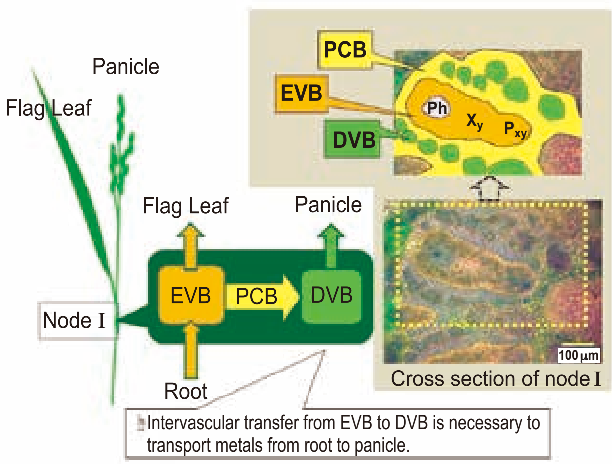

Fig.1. Interconnection of vascular bundles in node I. EVB: enlarged vascular bundle, PCB: parenchyma cell bridge, DVB: diffuse vascular bundle, Xy: xylem, Ph; phloem, Pxy; protoxylem.

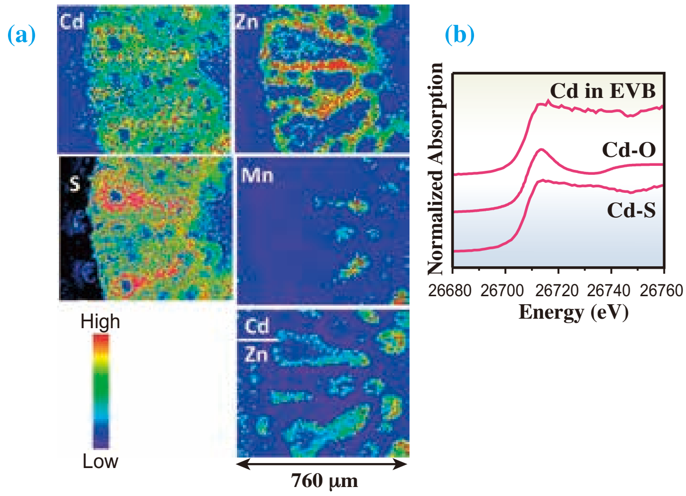

Fig. 2. **(a)** Distributions of cadmium, zinc, manganese, sulfur and cadmium-to-zinc ratio on the cross section of node I. **(b)** Cd *K*-edge μ-XANES spectra of reference materials (CdO and CdS) and Cd that accumulated in the xylem of enlarged vascular bundle.

Cd, Zn and Mn in node I. The accumulation of Mn in node I was minimal because the redirection of Mn in the node was not affected by any retardation processes, such as sequestration and insufficient transfer from cells of certain tissues to adjacent ones. Mn was observed to be preferentially transported toward the flag leaf. The restricted flow of Cd and Zn resulted in their accumulation in node I, indicating that the node redirected Cd and Zn. Cd and Zn were clearly discriminated in the node by the regulation of Cd transport, which is nonessential. Vascular or cytoplasmic sequestration with the S-containing ligand is known as an important mechanism for Cd detoxication [4,5]. The Cd in the xylem of the EVB might have been sequestrated in a vacuole in a S-containing ligand-bound form. Zn accumulation in the PCB may contribute to the maintenance of a relatively constant Zn concentration for transport to the grains. Once stored in the PCB, Zn is preferentially transported to panicles through the DVB, compared with Cd.

Our results show the first evidence indicating that the transport of Cd, Zn and Mn is controlled by the functional interconnection of vascular bundles in the rice nodes. Understanding the mechanisms governing Cd transport to rice grains is important for engineering rice cultivars with a reduced Cd concentration in the grains.

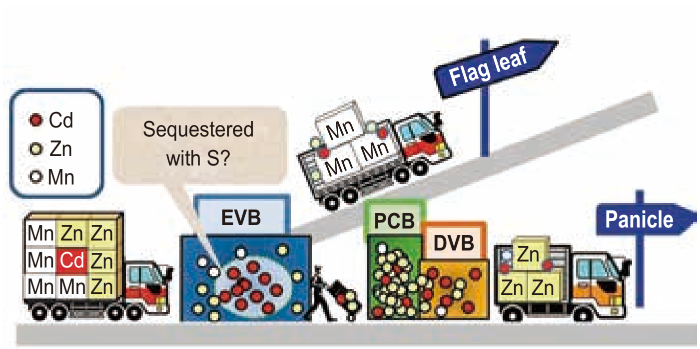

Fig. 3. Metal trafficking in node I.

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