Chapter 6
3D Images

Keywords 3D image · ^{109}Cd · ^{137}Cs · Rice · Grain · Distribution · Accumulation · IP image

6.1 3D Image of ^{109}Cd in a Rice Grain

Seeds of rice plants (*Oryza sativa* L. var. Nipponbare) grown in water culture were employed for 3D image construction. During the maturing process of the grain, after flowering, ^{109}Cd (1 MBq) was supplied to the water culture. After 24 h of treatment, the brown rice was harvested and subsequently embedded in resin under freezing conditions. The rice grain was sliced into sequential sections 5 μm in thickness (Fig. 6.1), and the sliced sections were removed successively every 100 μm and stored at −20 °C. The height of the whole grain was approximately 6 mm; therefore, the number of slices was approximately 1200 sheets when sliced every 5 μm. Out of these 1200 sheets, successive sheets were removed every 100 μm, and these 60 sheets were used to construct the 3D image.

Since the ionic form of nuclides can move inside the plant during the sectioning process, such as during fixation and dehydration, sample preparation and radiography were performed under frozen conditions to diminish radionuclide movement. After the samples were placed on an IP, the image produced in the IP was read by a scanner to obtain the radiographs. Then, the successive ^{137}Cs distribution images acquired from the IP were used to construct the 3D image employing ImageJ software.

Figure 6.2a and c show the sliced grain picture and the radiation images of 2 sliced grains taken by an IP, respectively. In each unit (red square), two horizontal and two vertical images of the two grains are shown. In each unit, the two images on the left side and right side are the grains 20 and 15 days after flowering, respectively, showing a horizontal (small round image) and a vertical (longer image) pair of images for each grain. When the picture and the radiograph image are superposed (Fig. 6.2b), it was

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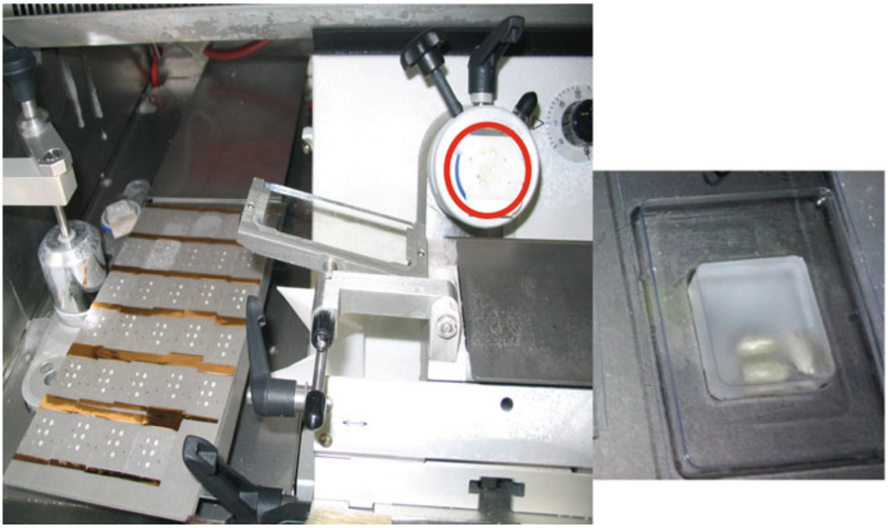

Fig. 6.1 Slicing the rice grain to construct 3D images. The grain was embedded in resin and sliced to 5 μm in thickness under freezing conditions

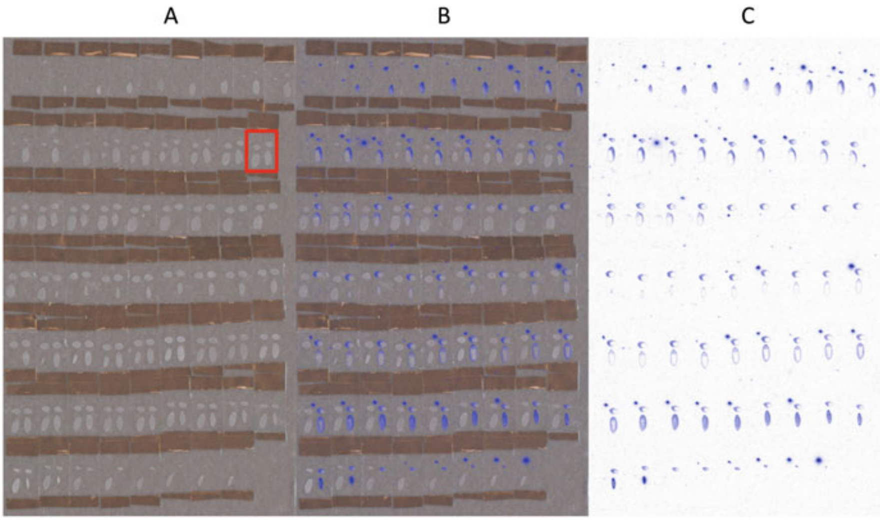

Fig. 6.2 Series of sliced grain images after 15 and 20 days of flowering [1] modified. For each small unit site, two pairs of slices were placed. The small and large slices in the unit are horizontally and vertically sliced grains. An example of the small site unit is shown in a *red square*. In each unit, two grains at each growth stage are shown: after 15 (right side) and 20 days (left side) of flowering. (**a**) Photograph of the sliced seeds; (**b**) radiograph image (**c**) superposed to a photograph of the sliced pictures (**a**); (**c**) ^{109}Cd radiograph image acquired by an IP

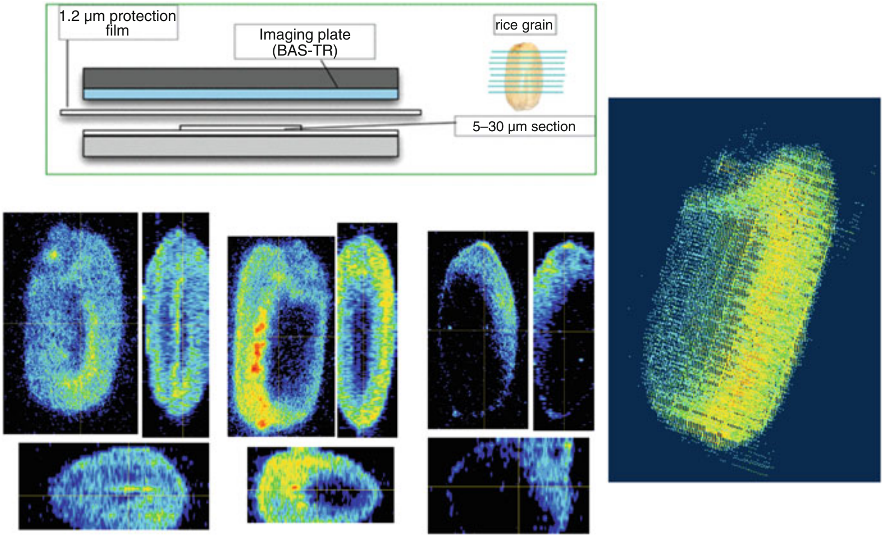

Fig. 6.3 3D image of ^{109}Cd in a rice grain constructed from the sliced image acquired by an IP [1] partially. In total, 62 images acquired by the IP were rearranged, and a 3D image was constructed. Upper: schematic illustration of the process to acquire the ^{109}Cd image in each slice; Lower right: 3D volume view; Lower left: orthogonal volume views. Pseudocolor was assigned to the radiation intensity

clear that there was hardly any ^{109}Cd observed in the left side grains in the unit, i.e., the grains 20 days after flowering.

The grains after 5, 10, 15, and 20 days were sliced in the same way, and from the series of approximately 60 images, 3D images were constructed. The volume of the endosperm increased from day 5 to 20 after flowering, along with the development of the grain. When 3D images were constructed, the decrease in ^{109}Cd accumulation at the endosperm was more clearly shown. However, the ^{109}Cd image of the grain 20 days after flowering was hardly observed. Figure 6.3 shows the 3D images of the grain after 5, 10, and 15 days. ^{109}Cd did not accumulate in the middle of the endosperm in any stage of the grains, and the accumulation amount of ^{109}Cs decreased during seed development.

The crystallization of the rice grain develops during the maturing process. Therefore, the relation between the ^{109}Cd distribution and crystallization was investigated. It was found that along with the formation of crystallization in the grain (Fig. 6.4), the accumulation of ^{109}Cd in the endosperm decreased, and ^{109}Cd was confined at the surface of the grain. Although the image shows the distribution profile of ^{109}Cd and does not reflect the route of the movement of the tracer, the imbalance in the ^{109}Cd decrease on one side of the grain suggested that the transferring function of the grain was lost from this site.

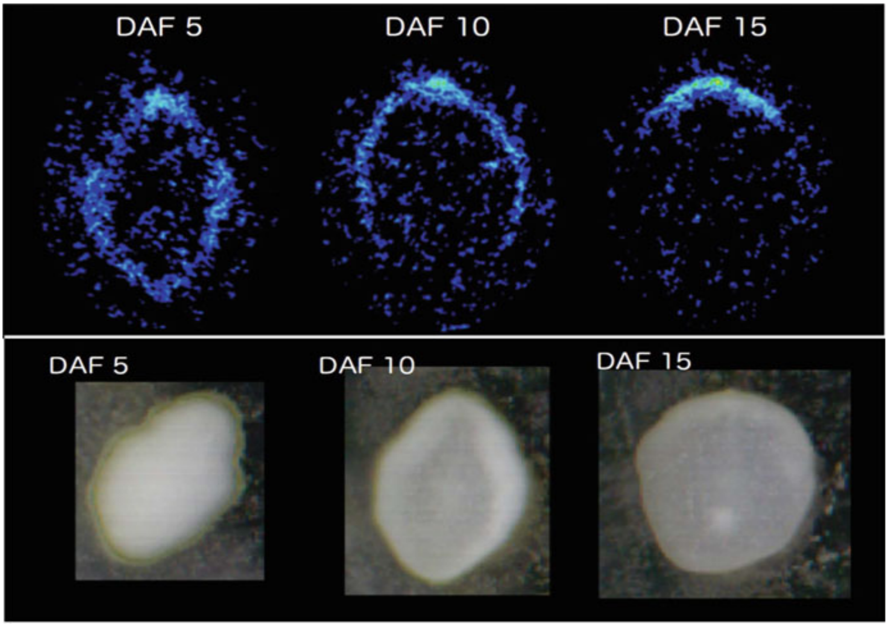

Fig. 6.4 Crystallization of a rice grain and the ^{109}Cd distribution [1]. Upper: ^{109}Cd distribution in a rice grain acquired by an IP; Lower: microscope image of a rice grain. During the ripening process of the grain, crystallization proceeds, and the color tone of the grain changes from an untransparent milky white to a partially transparent white color with the accumulation of ^{109}Cd to the surface and the decrease in the endosperm

6.2 3D Image of ^{137}Cs in a Rice Grain

In the case of ^{137}Cs, the rice plant was grown in water culture solution including ^{137}Cs (200 Bq/mL), and the grains were harvested 3, 5, 7, 9, 12, and 15 days after flowering. Then, each grain was sliced to 5 μm in thickness, and every 100 μm, successive slices were selected, in the same way as in the case of ^{109}Cd. Figure 6.5 shows the 3D image of the rice grain harvested 15 days after flowering. As shown in the figure, ^{137}Cs accumulated in the embryo and the outer bran layer. Before serving the grain as food, the periphery of endosperm is removed as bran through threshing. Therefore, the processed grain was estimated to contain a minimal amount of ^{137}Cs.

To compare the accumulation profile of ^{137}Cs with those of other elements in the grain, the distribution of K and Mg in the grain was analyzed by SEM-EDX (scanning electron microscopy/energy dispersive X-ray spectroscopy). Figure 6.6 shows the distribution of ^{137}Cs as well as of K and Mg in the horizontal plane of the grain. ^{137}Cs accumulated from an early stage of the maturing process of the grain, and the distribution was uniform throughout the grain. Distinct accumulation sites, including embryos, were not observed until the middle of the maturing process. Then, the accumulation of Cs at the grain surface and embryo began to increase,

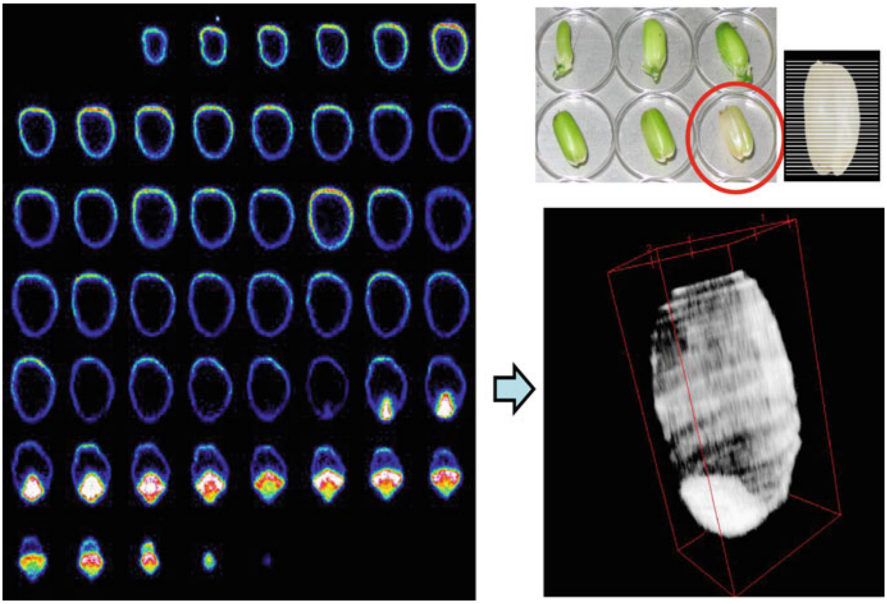

Fig. 6.5 Three-dimensional images of ^{137}Cs in brown rice. After 15 days of flowering, the rice grain was harvested, and the brown rice was sliced and exposed to an IP. Then, all images of the sliced sections were used to construct the 3D distribution of ^{137}Cs. The distribution of ^{137}Cs accumulated in the embryo, periphery of the endosperm, and surface of the brown rice is shown (most of these parts are removed as bran through thrashing before serving as a food staff)

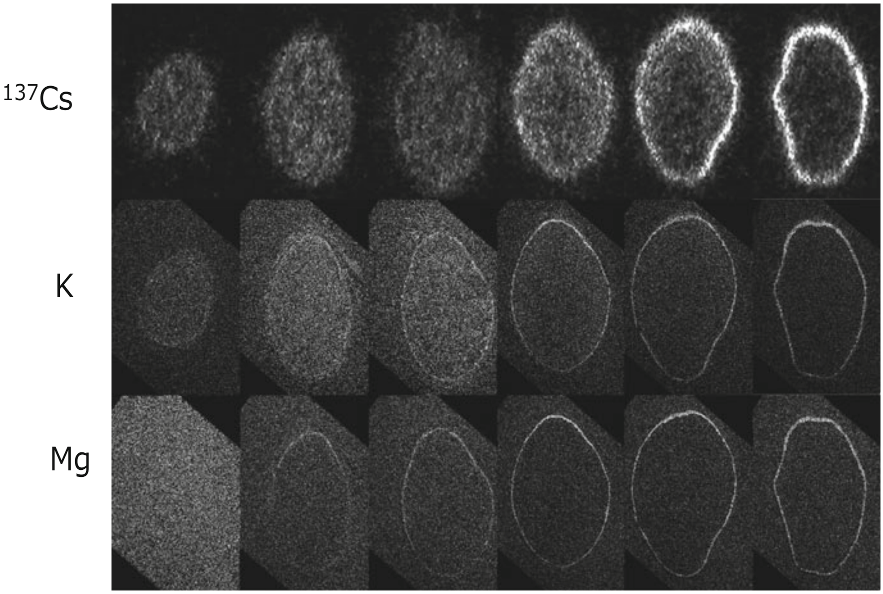

Fig. 6.6 Distribution of ^{137}Cs, K, and Mg in a rice grain. The distribution of ^{137}Cs, K, and Mg in the horizontal plane is shown during the development of a rice grain. The rice images were obtained 3, 5, 7, 9, 12, and 15 days after flowering from left to right. ^{137}Cs image was acquired by an IP. The K and M distributions were measured by scanning electron microscopy/energy dispersive X-ray spectroscopy (SEM-EDX)

along with a decrease in the Cs amount in the middle of the endosperm. On day 15 after flowering, the accumulation of Cs at the surface and embryo was completed. In the case of K, the distribution was uniform, similar to that of Cs, until the middle of the maturing process, and then the accumulation of K in the grain at the surface and embryo was observed. Since K and Cs are alkaline elements located in the same group in the periodic table, their chemical behavior was estimated to be similar. Magnesium was transferred to the grain later than K and Cs during the maturing process; however, the accumulation of Mg on the surface started from a rather early stage of maturation. The distribution of ^{137}Cs in the grain will be described in more detail in the next section.

Bibliography

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