Two models of Cd uptake by common plants and Hyperaccumulators

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Abstract. The Nramp family plays an important role in the absorption of cadmium in plants. Combining with biological process of cadmium uptake by plants, we are going to build a network which represents the system and then establish two multi-level dynamic models according to the different expression of Nramp genes between common plants and Cd-hyperaccumulators. We applied these two models to predict cadmium accumulation of common plants and Cd-hyperaccumulators, and it turned out that our models predicted the different cadmium uptake between two species of plants well. Our modelling methodology combines simplicity and flexibility with dynamic richness, making it well suited for directing future experiments.

Introduction

The Nramp family of metal transporters has been identified in several plant species, rice possesses seven putative Nramp genes. OsNramp1 expression was observed mainly in roots and was higher in the roots of a high-Cdaccumulating cultivar than in those of a low-Cd-accumulating cultivar [1]. OsNramp5 was mainly expressed in the roots and localized in the plasma membrane of exodermis and endodermis cells of the roots [2]. With different Nramp gene expressions, common plants and Cd-hyperaccumulators show different Cadmium absorption rates and accumulations. Experimental studies on this area are very few. However, much less has been done on a created model based on a network of living creatures.

In this work, we incorporated the existing theory describing the process of cadmium uptake by plants with researches on the Nramp family, and constructed two dynamic models of cadmium uptake. One model described the process of cadmium uptake by common plants, and the other was a description of the Cd-hyperaccumulators. The two models all recapitulate a comprehensive array of known behaviors and phenotypes. Since the model is made up of node-level information, this agreement serves as validation [3]. These two models reveal the different effects of OsNramp1 and OsNramp5 on the uptake of cadmium by common plants and Cd-hyperaccumulators.

Models

Assembly of the cadmium uptake signal transduction network. The first step in building a dynamic model is to construct the regulatory network that represents the system. A network is an abstraction of a system in which each element is represented as a node, and the relationship between each pair of interaction or regulation is represented by an edge. Edges in signal transduction networks are generally directed and signed. The members involved in cadmium uptake include proteins, entities, certain biological processes, some important inorganic compounds and the metabolic processes. In our network, positive edges correspond to activation, up-regulation, or biochemical synthesis, and are represented with a terminating arrowhead, while negative edges are shown as terminating in a solid circle which indicates deactivation, inhibition, or consumption. A relationship stimulated by another component of the network is represented by an edge starting from the stimulus node and incident on the stimulated edge.

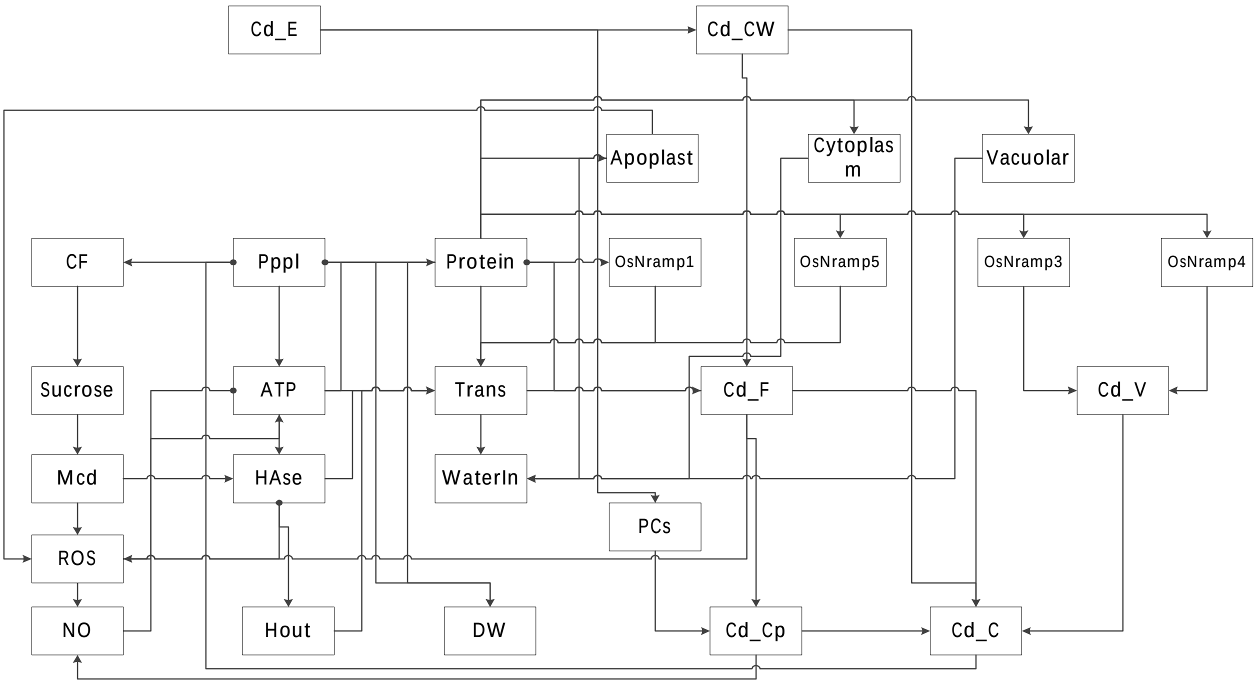

Fig. 1 Network of cadmium uptake process.

The resulting network shown in Fig. 1 is constituted by 27 nodes and 50 edges. A brief description of the biology represented by the network is as follows: The Nramp family of metal transporters has been identified in several plant species, rice possesses seven putative Nramp genes [1]. Different Nramp genes have different subcellular localizations, thus have different effects on cadmium accumulation. For example, OsNramp1 and OsNramp5 are located in the plasma membrane while OsNramp3 and OsNramp4 are located in the vacuole membrane. Thus OsNramp1 and OsNramp5 affect the intracellular free state of cadmium in cytoplasm, while OsNramp3 and OsNramp4 affect the cadmium accumulation in vacuole. In our research, the total accumulation of Cd (i.e. Cd_C) was composed of Cd that bound to the cell wall (i.e. Cd_CW), free state of cadmium in cytoplasm (i.e. Cd_F), cadmium accumulation in vacuole (i.e. Cd_V) and Cd combined with PCs to form complex (i.e. Cd_Cp). With the increase of cadmium accumulation Cd stress will cause diminished photosynthetic activity [4], thus preventing the production of ATP and H^+-ATPase. And then, protein synthesis will be inhibited; the number of metal transporter protein and stability of membrane will be influenced [5].

The difference of the two models. The difference between the models of common plants and Cd-hyperaccumulators laid in the different effects of OsNramp1 and OsNramp5 on Cd accumulation. For instance, OsNramp1 localized in the plasma membrane and the level of OsNramp1 expression was higher in high-Cd-accumulating indica cultivars such as Habataki than in low-Cd-accumulating japonica cultivars such as Sasanishiki[6]. The reflection of these in the models was that the effect of OsNramp1 on Cd that existing in a free state are different.

Analysis and Verification of Models

Two models revealed that the OsNramp1 and OsNramp5 had different effects on Cd uptake by common plants and Cd-hyperaccumulators. We studied the difference of Cd accumulations in two kinds of plants under different Cd concentrations which were caused by diverse OsNramp1 and OsNramp5 expressions. In order to understand the state of plants better we found two biomass as a reference. They were photosynthetic rate and dry weight. In Fig. 2, Fig. 3 and Fig. 4, the blue line represents the common plants, and the red line represents Cd-hyperaccumulators. Fig. 2 shows the Cd accumulations, photosynthetic rates and plant dry weights of the two species of plants under low Cd condition. From Fig. 2 (A), we conclude that the difference of the uptake rates between

Cd-hyperaccumulators and common plants is not very obvious. From Fig. 2 (B), the photosynthetic rate of common plants is diminished under this condition. At the same time, the dry weight growth of common plants has a tendency to slow down, while Cd-hyperaccumulators is almost not affected as we can see from Fig. 2 (C).

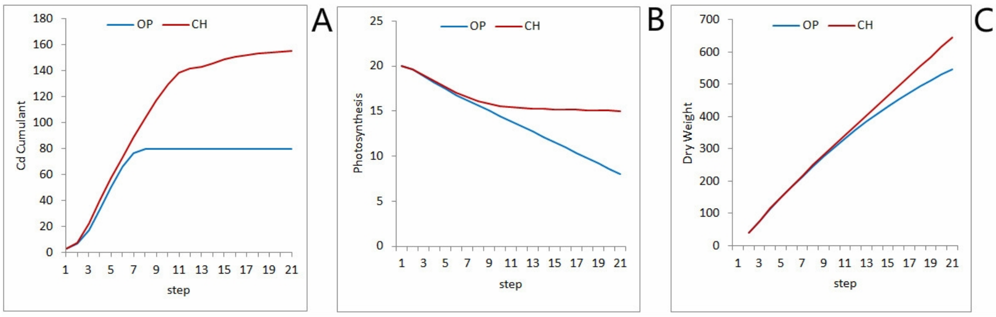

Fig. 2 Results at low Cd concentration.

When the Cd concentration in the environment increased we got Fig.3. we can see that the cadmium uptake rate of Cd-hyperaccumulators is significantly higher than common plants, which is caused by the OsNramp1 and OsNramp5. In Fig. 3 (B), the photosynthetic rate of common plants decreased rapidly, while the effect on Cd-hyperaccumulators is relatively small. At the same time, the dry weights of the two kinds of plants decrease significantly, especially the common plants, which is obvious in Fig. 3 (C). Combining the photosynthetic rate of common plants which decreases nearly to zero in Fig. 3 (B) and the increase of dry weight is nearly zero in Fig. 3 (C) we infer that common plants have died.

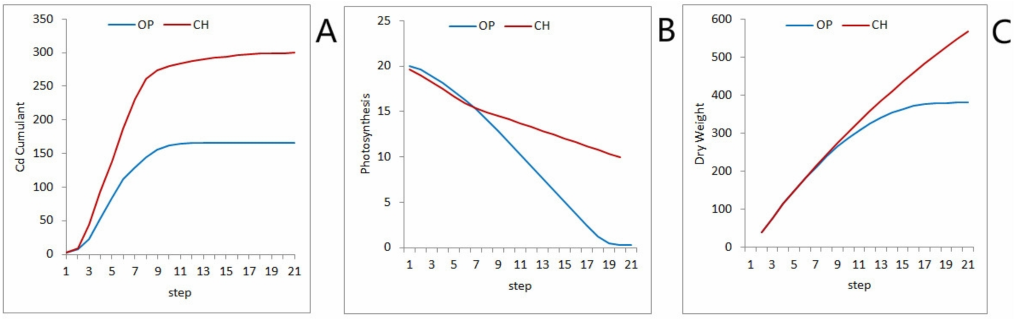

Fig. 3 Results at higher Cd concentration.

When concentration of Cd exceeds the maximum that the plant can tolerate, it appeared the situation shown in Fig. 4. The Cd uptake rates of the common plants and Cd-hyperaccumulators significantly decrease in Fig. 4 (A) compared with Fig. 3 (A) and Fig. 2 (A), while the absorption rate of the latter is still greater than that of the former. From Fig. 4 (B), we can obviously find the decrease of photosynthetic rate in common plants is much faster than Cd-hyperaccumulators, and both photosynthetic rate finally decrease to zero. In addition, the dry weights of two species of plants increase by nearly zero in Fig. 4 (C). We infer that both of the plants are death at such a high concentrations of Cd.

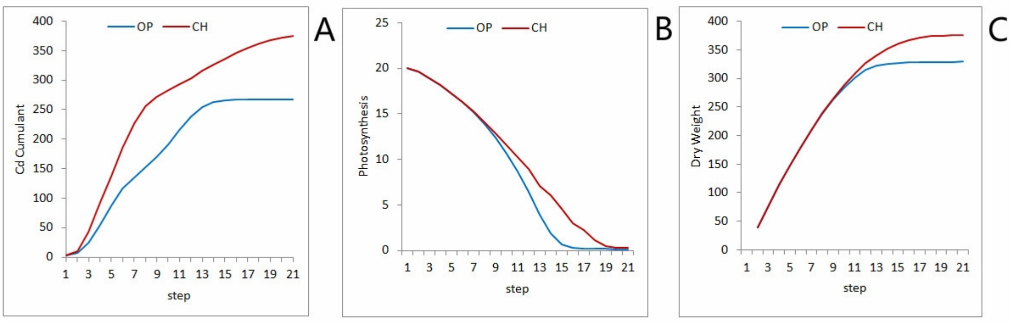

Fig. 4 Results at high Cd concentration.

Correctness verification of models. Shunhua Lin et al. Reported the effect of Cd on the photosynthetic rate of rice, and the results showed that Cd decreased the photosynthetic rate of plants [7]. When we compare Fig. 2 (B), Fig. 3 (B) and Fig. 4 (B), we can reach the same conclusion. The photosynthesis of the two species is affected by cadmium, and the photosynthetic rates decrease proportionally with the increasing of Cd concentrations, and the photosynthetic rate of common plants decrease more rapidly under the same level of Cd. Besides in the study of Xin Chen et al.[8], they found that the dry weight raise of plant decreased progressively with increasing Cd concentration which is also consistent with the predictions of our models.

Conclusions

Our models are based on the network in Fig. 1 which is built on the basis of existing theories that are about the biological process of cadmium uptake by plants, and distinguished by different effects of OsNramp1 and OsNramp5 on the uptake of Cd by two species of plants. By comparing the experimental results of other scholars with ours, the correctness of our models is well verified. In addition, our models not only can forecast cadmium accumulation, but also can compare the difference between common plants and Cd-hyperaccumulators of any other nodes in network you want to observe. More importantly, our models avoid the complexity and time consuming of biological experiments, meanwhile we can give the simulation results in a relatively short period of time.

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