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Tokushima University
Aichi Steel Corporation
Ishikawa Prefectural University
The University of Tokyo
Hokkaido University
Suntory Foundation for Life Sciences, Bioorganic Research Institute

Success in Developing a Next-Generation Fertilizer that Enables Agriculture in Poor Soil

The research groups of Professor Kosuke Namba of the Tokushima University Graduate School of Biomedical Sciences and Aichi Steel Corporation (President: Takahiro Fujioka) with Professor Takanori Kobayashi and others of Ishikawa Prefectural University Institute of Bioresource Engineering, Associate Professor Hiromi Nakanishi and others, Graduate School of Agricultural and Life Sciences, Faculty of Agriculture, the University of Tokyo, Professor Keiji Tanino and others, Faculty of Science, Hokkaido University, Yoshiko Murata and others, Research Fellow, Suntory Foundation for Life Sciences, Bioorganic Research Institute have jointly researched a natural iron chelator secreted from the roots of gramineous plants*1 "mugineic acid"*2, and an improved its chemical structure to develop an environmentally friendly iron chelator, "proline deoxymugineic acid (PDMA)".

Points of Research Results

- A fertilizer that allows crops to grow normally in poor alkaline soil[*3], which accounts for 30% of the world's land surface, has been successfully developed.
- A next-generation eco-friendly fertilizer has been developed based on the natural iron chelator, "mugineic acid", which is secreted from the roots of gramineous plants.
- This is an achievement that will lead to the solving of global food shortages, which is "2. Zero hunger" of the SDGs.

About 30% of the land surface of the world is occupied by alkaline soil, which is considered unsuitable for farming. In poor soil with high alkaline, as iron exists as insoluble iron which is insoluble in water, so plants hardly absorb iron from their roots and sometimes die. Therefore, in order to enable farming in alkaline soil, it was necessary to develop an iron chelator for agriculture that dissolves insoluble iron in the soil.

This time, our research group has demonstrated through cell activity tests, rice cultivation tests using alkaline soil, pilot field tests, etc. that PDMA is a breakthrough fertilizer that allows crops to grow normally even in poor soil with high alkaline. PDMA is expected to be put into practical use in the future as one means to solve world food problems.

The results of this research were published in the electronic version of the British scientific journal "*Nature Communications*" on March 10. (Refer to page 2 and later for details)

Effects of supplying PDMA in alkaline soil fields (4 weeks after spraying)

Without PDMA

Using PDMA

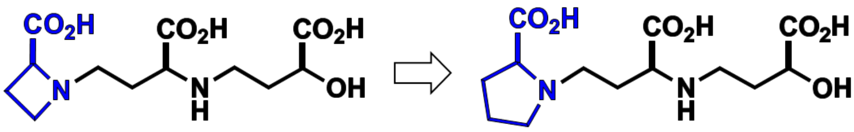
(Summary of Coverage)

[Background]

About 70% of the land surface of the world is considered to be poor soil unsuitable for farming, and half of it is considered to be alkaline soil. In alkaline soil, iron exists as iron hydroxide (III)[*4], which is insoluble in water, so plants hardly absorb iron from their roots, thereby causing iron deficiency. Since it is expected that food production will increase significantly if farming in alkaline soil becomes possible, the development of agricultural iron chelators that dissolve iron hydroxide in alkaline soil has been performed vigorously. However, the existing artificial iron chelators are not sufficiently effective, and they remain in the soil, so there was concern about the burden on the environment. On the other hand, grasses are known to secrete a natural iron chelator called mugineic acids from their roots then enables them to absorb iron efficiently. However, despite the discovery of mugineic acids more than 40 years ago, few attempts have been made to use mugineic types of acids as agricultural iron chelators. This is because mugineic acids and its derivatives can only be obtained in trace amounts from nature making it very expensive, and it is easily decomposed by microorganisms in the soil, so it was assumed that it was practically impossible to use mugineic acid as a fertilizer.

[Research Method]

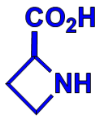
Using synthetic organic chemistry technology, our research group has developed an efficient chemical synthesis method for "deoxymugineic acid (DMA)", which is a natural product related to mugineic acids, and produced it using chemical synthesis. This made it possible to add DMA for soil application to rice, demonstrating for the first time in the world that administering DMA to rice in alkaline soils can enable it to recover from iron deficiency. However, the low stability of DMA in soil and the high cost of chemical synthesis were major obstacles for practical use of DMA as a fertilizer. The factors behind the low stability of DMA and the high synthesis cost are that the distortion of the 4-membered ring portion of DMA is very large, and L-azetidine-2-carboxylic acid (see the figure below), which is used as a raw material for chemical synthesis, is very expensive. Therefore, we synthesized various analogs in which we replaced L-azetidine-2-carboxylic acid with a stable and inexpensive amino acid, and evaluated its performance. As a result, we found that inexpensive proline deoxymugineic acid (PDMA), in which we changed L-azetidine-2-carboxylic acid to L-proline (see the figure below), showed a better growth-promoting effect than natural DMA.



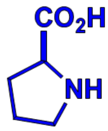
"Deoxymugineic acid (DMA)", a type of mugineic acid

"Proline deoxymugineic acid (PDMA)", which we successfully developed

Synthetic Raw Material



L-azetidine-2-carboxylic acid
(very expensive)



L-Proline
(inexpensive)

[Research Results]

Since the natural amino acid L-proline is available cheaply, the cost of synthesizing PDMA can be reduced to 1/1,000 to 1/10,000 of DMA, solving the biggest problem of the cost of raw materials. In addition, cell tests have shown that PDMA is effective not only in rice but also in all grasses such as corn and barley. In addition, natural mugineic acids are decomposed by microorganisms in the soil in one day, but as PDMA takes about one month to decompose, the effects are maintained for a long time. Existing general iron chelators are not decomposed by microorganisms and remain in the soil, so there is concern about the burden on the environment, but since PDMA decomposes in one month, it can be used as an environmentally friendly fertilizer. As it became possible to supply a large amount of PDMA, a pilot field with alkaline soil was created, and an outdoor cultivation test was also conducted, using rice. As a result, it was shown that PDMA shows an excellent effect in recovering from iron deficiency, about 10 times that of existing iron chelators, and that adding PDMA made it possible to harvest rice. In other words, rice could be harvested when actually using alkaline soil.

Effects of supplying PDMA to rice in alkaline soil fields (4 weeks after spraying)

Without PDMA

Using PDMA

[Expectations for the Future]

The world's population is increasing dramatically and is expected to reach 10 billion by 2050. As a result, food production cannot keep up with population growth, and it is certain that serious food shortages will occur in the near future. Since the expansion of agricultural land via deforestation promotes global warming, a new approach to increasing food production levels is being sought. This research utilizes land that was previously unsuitable for agriculture, and is considered to be extremely unlikely to cause serious environmental destruction. It is clear that if it is possible to improve agricultural productivity in alkaline soil, which accounts for about 30% of the world's land, it will have a tremendous effect on increasing food production throughout the world. In addition to contributing to the SDGs "2. Zero hunger", it is also expected that the reduction of carbon dioxide due to the greening of poor soil will prevent global warming, contributing to "13. Climate action". It is also expected to contribute to "15. Life on land" by preventing desertification and resolve energy problems by increasing biomass production which will contribute to "7. Affordable and clean energy". Based on the development of PDMA, we will scrutinize the administration conditions according to the different soils around the world and study the manufacturing method on an industrial scale, and also contribute to the greening of poor soil around the world and the securing of stable food supply.

Research Paper Title:

Development of a mugineic acid family phytosiderophore analog as an iron fertilizer

Author: Name (Affiliation)

Aichi Steel Corporation, Tokai-shi, Aichi, Japan

Motofumi Suzuki & Akane Mera

Department of Pharmaceutical Sciences, Tokushima University, Tokushima, Japan

Atsumi Urabe, Sayaka Sasaki, Ryo Tsugawa, Satoshi Nishio, Haruka Mukaiyama, Masaki Takeuchi, Keijo Fukushima, Binod Babu Shrestha, Atsushi Nakayama, Hiromichi Fujino & Kosuke Namba

Bioorganic Research Institute, Suntory Foundation for Life Sciences, Soraku-gun, Kyoto, Japan

Yoshiko Murata & Takehiro Watanabe

Ishikawa Prefectural University, Nonoichi, Ishikawa, Japan

Hiroshi Masuda, May Sann Aung, Takanori Kobayashi & Naoko K. Nishizawa

Graduate School of Chemical Sciences and Engineering, Hokkaido University, Sapporo, Japan

Michika Kanaki & Kaori Kobayashi

The University of Tokyo, Bunkyo-ku, Tokyo, Japan

Yuichi Chiba, Hiromi Nakanishi & Naoko K. Nishizawa

Faculty of Science, Hokkaido University, Sapporo, Japan

Keiji Tanino

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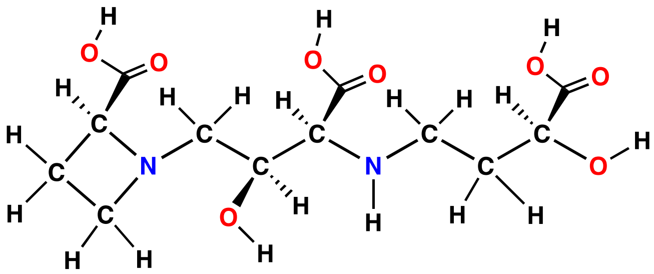
[Terminology Explanations]

*1 Iron chelator "Chelate" means "crab scissors" in Greek. A substance that surrounds iron ions and enables them to exist stably even in alkaline soil.

*2 Mugineic acid A natural iron chelating substance secreted by plants. In 1976, Dr. Seiichi Takagi of Iwate University discovered it as "an acid secreted from the roots of wheat", and in 1978, the chemical structural formula was decided by Dr. Tsunematsu Takemoto and others, and it was given this name. "Mugine" means "roots of wheat" in Japanese.



Chemical structural formula of mugineic acid

∗3 alkaline soil This is a general term for alkaline soils with a pH of 7 or higher, and corresponds to calcareous soils and salt-accumulated soils. Most of the soil in desert areas is also alkaline. Aalkaline soil is found all over the world, including the Midwestern United States, the Mediterranean coast, northern China, and the continent of Australia, and occupies about 30% of the world's land. In acidic soil with low pH, plants can absorb iron from their roots because iron is dissolved, but in alkaline soil, as iron is hardly dissolved, plants hardly absorb iron, resulting in iron deficiency. When the pH increases by 1, the amount of iron dissolved decreases to 1/1,000 or less.

∗4 Iron hydroxide It is the name of the hydroxide of iron, and there are iron hydroxide (II) and iron hydroxide (III) depending on the number of iron oxides. Iron hydroxide in alkaline soil is iron hydroxide (III). Iron hydroxide (III) is a conventional name, and the actual structure is iron oxide-hydroxide (III) (FeO(OH)). It is so-called red rust and is extremely difficult to dissolve in water under alkaline conditions.