Cultivation of Selenium-Enriched Vegetables in Large Scale

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Abstract

This study was conducted to establish a practical method to cultivate selenium-enriched vegetables in a large scale. Due to the toxicity of inorganic selenium compounds used as a source of selenium, concerns are the safety of agricultural workers operating the system and also effects on environments, especially the pollution of the ground water.

Barium selenate and barium selenite were selected as the selenium source for the cultivation because of the easiness of handlings, a slow diffusion into environments and the constant release of selenium in soil for an extended period of time. The cultivation was carried out in a concrete 10mx15mx1m frame equipped with a water tank beneath the frame. The frame was filled with a soil. The water tank was used to store the permeated water from the soil. The system was set in the ground. Barium selenate (500mg/m² as selenium) and barium selenite (500mg/m² as selenium) were applied on the soil and then the soil was plowed.

Garlic and onion were planted in fall and harvested in the next autumn. Cabbage was planted in early winter and harvested in the next spring. Peanut, pepper, ginger, tomato, and eggplant were planted in spring and harvested in the late summer. Through the study period, selenium contents in the water permeated into the tank from the soil (Soil Water) were monitored. The selenium content in the soil in the frame was also determined. The selenium content in Soil Water reached the maximum value (1.4ppm) 14 months after the application of the selenium salts. On the other hand, the total selenium in the soil was slightly decreased during this period.

Selenium contents in fresh edible portions of harvested vegetables as follow:
Garlic 130ppm, onion 20ppm, peanut 57ppm, pepper 7.1ppm, ginger 2.7ppm, cabbage 1.3ppm, tomato 2.9ppm, and eggplant 3.7ppm.

Major selenium compounds in these vegetables are selenoamino acids and their derivatives. Organic selenium components in the soil would participate with the selenium absorption by the vegetables.

Key words: Selenium, selenium-enriched, barium selenite, barium selenate, garlic, vegetables

Introduction

The growth of selenium-enriched vegetables has been studied by using soluble alkali-metal salts of selenium.

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Hamilton and his coworkers grew eighteen garden vegetables on the soil containing potassium selenate (1). Selenium-enriched garlic was grown by using sodium selenate in tubs filled with peat moss and vermiculite and the cancer prevention study was carried out using its extract (2). In a hydroponical cultivation, sodium selenate was used to grow ramps.
(3). The reason why sodium selenate was selected is that sodium selenate is very soluble in water and is more resistant to reduction compared with sodium selenite. From a viewpoint of efficiency, the plants absorbed a very small portion of the applied selenium in these experiments, however.

Today selenium is taken via the usual food system that ultimately rests on higher plants. But in the case of urgent mass deficiency of selenium, the ordinary food production system would not meet the demand. The production of selenium-enriched foods in a large scale has never been reported yet, nevertheless.

Recent progress of selenium chemistry makes the speculation of chemical species in selenium-enriched plants easier. Selenoamino acids and their derivatives are reported as major selenium components of some selenium-enriched plants. Ip and his collaborators reported that the major selenium component in high-selenium garlic is γ-Se-methylselenocysteine and this compound is a naturally occurring anticancer agent by the animal experiment (4). Whanger reported the existence of Se-methylselenocysteine in selenium-enriched ramps and this compound does not accumulate in animal tissues (3). Broccoli was grown in the selenized soil with sodium selenate and tested for anticancer agent, though the active component was not identified yet (5).

These studies show the usefulness of selenium-enriched plants for drug discovery as a source of organic selenium compounds. We plan to supply selenium-enriched foods in a large scale to use for nutritional studies and also a source for drug screening of organic selenium compounds.

The safety of the agricultural workers and the protection of environments were primarily considered at the design of a cultivation system of selenium-enriched vegetables.

Material and Methods
We constructed a concrete frame (15mx10mx1m) equipped with a water tank beneath the frame (shown in Figure 1) and a pump to circulate the water stored in the tank. The frame was filled with pebbles, sand, and soil in order. The system was set in the ground.

**FRAME FOR CULTIVATION**

![Diagram of cultivation frame](image)

Figure 1. Scheme of cultivation frame

The authors applied Selcote Ultra(6) (a mixture composed of sodium selenate, barium selenate and inert inorganic material) on the soil of this system at first but the rapid escape of selenium from the frame to the tank was observed (7). The rapid escape of the selenium requires not only frequent applications of selenium on the soil but also increase the chance of the pollution of environments. Considering the easiness of handlings and the constant release of selenium for an extended period of time, low soluble selenium salts were selected as selenium sources finally. As barium selenite is easily adsorbed by soil and it released soluble selenium in soil for an extended period of time, it hardly escapes out of the frame. Barium selenite is also sparingly soluble but it can supply selenium to plants at a considerable rate.

Five hundred milligrams of BaSeO₃ and BaSeO₄ each per square meter were applied on the surface of the new soil after replacing the old selenized soil with Selcote Ultra in the frame. Then the soil was turned over. Slaked lime and chemical fertilizers were applied thereafter.

Garlic and onion were planted in the autumn of 2000 and 2001 and harvested the next early summer, respectively. Peanut was planted in the spring of 2001 and harvested in the fall of the same year. Cabbage was planted in the early winter of 2002 and
harvested in April of 2003. Eggplant, tomato, ginger, peanut and pepper were planted in the spring of 2002, and harvested in the fall of 2002 respectively. The water permeated from the soil was stored in the tank (denoted hereafter as Soil Water) and circulated with a pump if the concentration of selenium in Soil Water was over 0.1 ppm. Selenium contents in the soil and in Soil Water were analyzed by ICP method.

Results

The selenium contents in the soil were 11ppm just after the first application and 10ppm one year after the application of selenium. Selenium contents in Soil Water changed dramatically as shown in Figure 2. The selenium content in Soil Water reached the maximum value of 1.4ppm at 14 months after the application of the selenium compounds and then gradually decreased.

Selenium contents in edible portions of harvested vegetables were also determined and the results were shown in Table 1. The selenium content (72ppm) in the garlic cultivated in the year of the application (2001) of selenium was lower than that (130ppm) in the garlic cultivated one year later from the selenium application (2002). A close relationship is observed between the selenium contents in harvested vegetables and the selenium contents in Soil Water. The selenium contents in vegetables are also dependent on the species of plants. Garlic absorbed selenium effectively and grew without any retardation. Onion also absorbed selenium efficiently but this vegetable showed a weak stunting (growth retardation). The selenium content of some plants was also dependent on the timing of picking in the same season as shown in cases of tomato and eggplant (Table 1). While the plants were getting older, the absorption rate of selenium was getting slower.

Major selenium components of the vegetables are selenoamino acids, for example Se-methyl selenocysteine, selenomethionine, and their derivatives (8).

Figure 2. Time course of selenium contents in Soil Water

<table>
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<th>Table 1. Selenium in edible portions of vegetables</th>
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<td>Tomato I</td>
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Discussion

Barium salts of selenium are sparingly soluble in water and released soluble selenium species are at the level of a few ppm at equilibrium. In these experiments, however, vegetables have absorbed selenium at considerable rate. This is because plants absorb selenium as soon as free selenium is released from the salts in the soil. That is, the selenium absorption by plants is a kinetically controlled process but not a thermodynamically controlled process. This mechanism also works to reduce the diffusion of selenium into the ground water. As most of applied selenium in this case remains as a solid in the frame, the control of cultivation system is easier than the use of highly soluble selenium salts such as sodium selenate or sodium selenite. Because soluble selenium salts often spill the surrounding environment by the overflow from the frame caused by big rainfalls.
For understanding of the mechanism of selenium absorption by plants, the participation of organic selenium components was suggested. If the vegetables absorbed the applied inorganic selenium salts only, the selenium content in garlic of the first year (2001) would be higher than that of the second year (2002). After the harvest of garlic, cloves were taken up and stored but leaves and stems were left in the frame. This residual material would be decomposed into organic soluble selenium compounds by microorganisms in the soil. Nonetheless, these facts cannot explain the sudden appearance of such a big selenium peak in Soil Water after one year of the selenium application completely. This system is expected to enable the supply of selenium-enriched foods in a large scale.

References
6. This is the registered name of the product by Crop Care Holdings, Ltd. New Zealand.