Radionuclide Analysis on Bamboos following the Fukushima Nuclear Accident

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Abstract

In response to contamination from the recent Fukushima nuclear accident, we conducted radionuclide analysis on bamboos sampled from six sites within a 25 to 980 km radius of the Fukushima Daiichi nuclear power plant. Maximum activity concentrations of radionuclides 134Cs and 137Cs in samples from Fukushima city, 65 km away from the Fukushima Daiichi plant, were in excess of 71 and 79 kBq/kg, dry weight (DW), respectively. In Kashiwa city, 195 km away from the Fukushima Daiichi, the sample concentrations were in excess of 3.4 and 4.3 kBq/kg DW, respectively. In Toyohashi city, 440 km away from the Fukushima Daiichi, the concentrations were below the measurable limits of up to 4.5 Bq/kg DW. In the radiocesium contaminated samples, the radiocesium activity was higher in mature and fallen leaves than in young leaves, branches and culms.

Introduction

On March 11, 2011, several large earthquakes hit the northeast coast of Honshu, Japan, followed by a massive tsunami along the east coastline of Japan. The tsunami that damaged the Tokyo Electric Power Company (TEPCO) Fukushima Daiichi nuclear power plant caused huge releases of radionuclides into the environment of Japan [1]. However, the accident also had global effects as suggested by the detection of radioxenon (133Xe) in Washington, USA [2] and Vancouver, Canada [3], and of radiodine (131I) and radiocesium (134Cs, 137Cs) in California and Washington, USA [4], Thessaloniki, Greece [5], Bremen, Germany [6], Huelva, Spain [7] and Krasnoyarsk, Russia [8]. The spread and effects of the 134Cs and 137Cs radionuclides have become of prime interest because of their dose and long half-lives of 2 and 30 years, respectively. Indeed, we are faced by the serious problem of radiocesium attachment to and/or uptake by agricultural plants [9].

Bamboo is a fast-growing renewable biomass that is widely distributed throughout Asia. In Japan, the above-ground biomass of Phyllostachys pubescens has been estimated at 116.5 t dry matter ha⁻¹ for culms and with a gross annual soil respiration of 52.3 t dry CO₂ ha⁻¹ [10]. The large quantities of bamboo leaves that are often used for bamboo grass tea or as cattle food are indicative of their huge environmental impact. Also, the fallen leaves that are spread in the environment might enter the human food chain via soil decomposer. Here, we report the results of the radionuclide analysis on bamboos following the Fukushima nuclear accident.

Methods

Ethics Statement

No specific permits were required for the described field studies: a) no specific permissions were required for these locations/activities; b) location are not privately-owned or protected; c) the field studies did not involve endangered or protected species.

Plant samples

We sampled leaves and branches of Phyllostachys nigra var. henonis Staph (Hachiku) in Minamisouma city, Fukushima Prefecture (25 km from Fukushima Daiichi) on 24th July 2011; Pleioblastus chino Makino (Azumanezasa) in Fukushima city, Fukushima Prefecture (65 km from Fukushima Daiichi) on 24th July 2011; Pleioblastus aurea Carr. Ex A. Riv. Et C (Hoteichiku) in Aizuwakamatsu city, Fukushima Prefecture (100 km from Fukushima Daiichi) on 24th July 2011; Pleioblastus simonii Nakai (Medake) in Kashiwa city, Chiba Prefecture (195 km from Fukushima Daiichi) on 1st, July, 21st July and 24th August 2011; Pleioblastus simonii Nakai (Medake) in Toyohashi city, Aichi Prefecture (250 km from Fukushima Daiichi) on 4th August 2011; Pseudosasa japonica f. pleioblastoides Muroi (Menyadake) in Beppu city, Oita Prefecture (980 km from Fukushima Daiichi) on 5th September 2011 (Fig. 1). New leaves described in this report were estimated to have emerged approximately two weeks before collection. The heights of all bamboo at collection were 3 to 5 m. Before radioactive measurements, all samples were dried at 60°C (dry oven, SANYO, MOV-112S) for 24 hours.
Radioactive measurements

The samples were analyzed by gamma spectrometry, equipped with a high purity germanium detector (Princeton Gamma-Tech, IGC-30180) and a multi-channel analyzer (Canberra, DSA-1000). The detector was shielded with 5 cm of lead to reduce background contributions from the surroundings. For determination of $^{134}$Cs activity concentrations, gamma-ray energies of 604.70 and 795.85 keV were used. The $^{137}$Cs activity concentrations were determined from the 661.66 keV peak energies. The samples were measured for a period of 7,200 seconds.

We cite data of the air dose rate 1 m above the ground surface for Minamisouma, Fukushima, and Aizuwakamatsu cities, opened by the Japanese Ministry of Education, Culture, Sports, Science
and Technology (MEXT) [11]; the data for Kashiwa city, opened by The University of Tokyo [12]; the data for Toyohashi city, opened by Aichi Prefecture [13]; and the data for Beppu city, opened by Oita Prefecture [14]. All air dose rates were measured using portable survey meters from late June to mid-August, 2011.

### Results

Typical gamma-ray spectra from mature leaves are shown in Figure 2A and B. The $^{134}$Cs and $^{137}$Cs were clearly detected as peaks of gamma-ray energy in the samples obtained on 24th July.

### Table 1. The radioactivity concentrations of bamboo leaves and branches.

| Material                  | Sampling date | Sampling area     | Cs-134 (Bq/kg DW) | Cs-137 (Bq/kg DW) | Cs-134/Cs-137 |
|---------------------------|---------------|-------------------|-------------------|-------------------|---------------|
| Mature leaves of Hachiku  | July 24, 2011 | Minamisouma city  | 63500±1790        | 74600±1890        | 0.851         |
| Young leaves of Hachiku   | July 24, 2011 | Minamisouma city  | 11100±969         | 12600±973         | 0.881         |
| Branches of Hachiku       | July 24, 2011 | Minamisouma city  | 10600±365         | 12300±367         | 0.862         |
| Mature leaves of Azumanezasa | July 24, 2011 | Fukushima city    | 71100±1560        | 79100±1570        | 0.899         |
| Young leaves of Azumanezasa | July 24, 2011 | Fukushima city    | 3080±747          | 2880±723          | 1.07          |
| Branches of Azumanezasa   | July 24, 2011 | Fukushima city    | 9130±338          | 10200±336         | 0.898         |
| Mature leaves of Hoteichiku | July 24, 2011 | Aizuwaikamatsu city | 4690±610        | 5600±633          | 0.838         |
| Young leaves of Hoteichiku | July 24, 2011 | Aizuwaikamatsu city | <32.0           | <29.0             | -             |
| Branches of Hoteichiku    | July 24, 2011 | Aizuwaikamatsu city | 501±90.7        | 539±85.2          | 0.929         |
| Mature leaves of Medake -1 | July 1, 2011  | Kashiwa city      | 3440±224          | 4330±268          | 0.794         |
| Young leaves of Medake -1 | July 1, 2011  | Kashiwa city      | 764±109           | 801±115           | 0.953         |
| Branches of Medake -1     | July 1, 2011  | Kashiwa city      | 1140±65.0         | 1310±70.5         | 0.874         |
| Mature leaves of Medake -2 | July 21, 2011 | Kashiwa city      | 3230±242          | 3550±253          | 0.908         |
| Young leaves of Medake -2 | July 21, 2011 | Kashiwa city      | 857±124           | 922±118           | 0.930         |
| Branches of Medake -2     | July 21, 2011 | Kashiwa city      | 977±72.8          | 1150±76.1         | 0.852         |
| Fallen leaves of Medake -1 | July 21, 2011 | Kashiwa city      | 2790±202          | 3300±219          | 0.845         |
| Fallen leaves of Medake -2 | July 21, 2011 | Kashiwa city      | 2810±199          | 3240±216          | 0.867         |
| Fallen leaves of Medake -3 | July 21, 2011 | Kashiwa city      | 3200±235          | 3790±255          | 0.844         |
| Mature leaves of Medake -1 | August 20, 2011 | Toyohashi city | <4.50            | <4.50             | -             |
| Young leaves of Medake -1 | August 20, 2011 | Toyohashi city | <2.40            | <2.40             | -             |
| Branches of Medake -1     | August 20, 2011 | Toyohashi city | <0.600           | <0.600            | -             |
| Mature leaves of Medake -2 | August 20, 2011 | Toyohashi city | <3.80            | <3.80             | -             |
| Young leaves of Medake -2 | August 20, 2011 | Toyohashi city | <5.00            | <5.00             | -             |
| Branches of Medake -2     | August 20, 2011 | Toyohashi city | <1.50            | <1.50             | -             |
| Mature leaves of Menyadake -1 | September 5, 2011 | Beppu city | 249±101        | 286±102           | 0.845         |
| Young leaves of Menyadake -1 | September 5, 2011 | Beppu city | <2.40            | <2.40             | -             |
| Branches of Menyadake -1  | September 5, 2011 | Beppu city | <0.400           | <0.400            | -             |
| Mature leaves of Menyadake -2 | September 5, 2011 | Beppu city | <2.80            | <2.80             | -             |
| Young leaves of Menyadake -2 | September 5, 2011 | Beppu city | <1.80            | <1.80             | -             |
| Branches of Menyadake -2  | September 5, 2011 | Beppu city | <0.400           | <0.400            | -             |

Because of space limitation, the species names are shown as Japanese names. Please refer to Methods for their scientific names. doi:10.1371/journal.pone.0034766.t001

### Table 2. The radioactivity concentrations in the inner and outer layers of the culms of Pleioblastus simonii Nakai (Medake) sampled in Kashiwa city.

| Material       | Sampling date | Cs-134 (Bq/kg DW) | Cs-137 (Bq/kg DW) | Cs-134/Cs-137 |
|----------------|---------------|-------------------|-------------------|---------------|
| Outer layer -1 | August 24, 2011 | 206±143          | 225±109           | 0.917         |
| Outer layer -2 | August 24, 2011 | 96.8±38.0        | 136±59.9          | 0.711         |
| Outer layer -3 | August 24, 2011 | 55.4±6.54        | 96.4±7.97         | 0.575         |
| Inner layer -1 | August 24, 2011 | 249±67.7         | 282±74.7          | 0.885         |
| Inner layer -2 | August 24, 2011 | 242±101          | 286±102           | 0.845         |
| Inner layer -3 | August 24, 2011 | 107±27.2         | 118±26.0          | 0.903         |

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from Minamisouma city (Fig. 2A), but were below the measurable limits in the 20th August samples from Toyohashi city (Fig. 2B). Unfortunately, we could not determine the quantity of 137Cs because of its low signal to noise ratio (Fig. 2), as 134Cs was not derived from the nuclear accident but from its natural occurrence at 0.0117 percent, and has an intraorgan behavior similar to that of stable potassium. Table 1 shows the activity concentrations of bamboo leaves and branches from the various sampling sites from around early July to early September, 2011. Strikingly high activity concentrations were obtained in samples from Minamisouma and Fukushima cities near the Fukushima Daiichi nuclear power plant. The highest 134Cs and 137Cs activities were 71.1 and 79.1 kBq/kg dry weight (DW) in mature leaves sampled in Fukushima city, respectively. In Aizuwakamatsu and Kashiwa cities, radioactivity activities were one order lower than those in Minamisouma and Fukushima cities. In Toyohashi and Beppu cities, radioactivity activities were below the measurable limits of up to 4.50 Bq/kg DW. The radioactivity activities tended to increase with the rise in air dose rates at the sampling sites (Fig. 3).

In the radioactivity contaminated samples, leaves showed higher activities than branches (Table 1) and culms (Table 2) and, among these, mature and fallen leaves showed higher activities than young leaves (Table 1).

To check whether the bamboos absorbed the radioactivity or not, we split the outer layer of the culms with a cutter knife to separate them into inner and outer culm layers. The activities within the inner layers were comparable to those in the outer layers (Table 2), suggesting radioactivity uptake.

Discussion

In this study, we report the radioactivity contamination of bamboo samples within a 25 to 900 km radius of the Fukushima Daiichi nuclear power plant. It has recently been reported that the 134Cs and 137Cs activity concentrations of azalea leaves collected in Chiba city, 220 km away from the Fukushima Daiichi, were 3.35 and 3.78 kBq/kg fresh weight, respectively [15]. These levels are comparable to our bamboo samples taken from Kashiwa city, 195 km away from the Fukushima Daiichi. Our results indicated that radioactivity contamination in mature and fallen leaves were higher than young leaves. It is possible that young leaves had not yet emerged at the time of the accident so that direct deposition from radioactive fallout would have been negligible. On the other hand, the activity within the inner culm layers suggests the uptake of radioactivity by bamboo in Kashiwa, 195 km away from the Fukushima Daiichi (Table 2). Cesium is an alkaline metal, and is present as a monovalent cation in all soils. Because of its similarity with its nutrient analogue, potassium, a considerable amount of radioactivity is thought to have been taken up by the bamboo from contaminated soil. A recent study reported the uptake of radioactivity by emerged leaves of 14 plant species collected 220 km away from the Fukushima Daiichi, and suggested that the translocation velocity of radioactivity varied among the species tested [15]. Our results may be in accord with results from experimental field-grown rice plants that showed a lower translocation velocity of 137Cs than potassium [16].

The mature leaves of bamboo are often used to prepare bamboo grass tea. The radioactivity activity concentrations of the bamboo leaves from Minamisouma, Fukushima, Aizuwakamatsu and Kashiwa were over 500 Bq/kg, a temporary regulatory value decided by the Japanese Ministry of Health, Labour and Welfare (MHLW). As the effective dose coefficients for ingestion of 134Cs and 137Cs are 0.019 and 0.013 μSv/Bq, the effective doses from the 200 mg amounts that are roughly used for a cup of tea prepared from milled tea powder from Fukushima and Kashiwa cities would be 0.476 and 0.0243 μSv, respectively. If just six cups of the bamboo grass tea from Fukushima city are consumed every day, the radiation dose from the tea would be in excess of 1 mSv/year. Therefore, we consider it preferable to avoid the regular drinking of bamboo tea from highly contaminated areas surrounding the Fukushima nuclear plant.

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Author Contributions

Conceived and designed the experiments: TH. Performed the experiments: TH. S. Higaki MH KA. Analyzed the data: S. Higaki MH. Contributed reagents/materials/analysis tools: S. Higaki MH S. Hasezawa. Wrote the paper: TH.

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