

## A NAA collaborative study in white rice performed in seven Asian countries

J. H. Moon · M. Ebihara · B. F. Ni ·  
B. Arporn · P. Setyo · R. M. Theresia ·  
B. S. Wee · N. A. Abd. Salim · P. C. B. Pabroa

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Since 2000, collaborative studies for applying NAA have been performed through the Forum for Nuclear Cooperation in Asia (FNCA) sponsored by the Japanese Government. White rice is a main food for Asians and thus was selected as a common target sample for a collaborative study in 2008. Seven Asian countries including China, Indonesia, Japan, Korea, Malaysia, Philippines and Thailand, are greatly concerned about the composition of arsenic, heavy metals, and essential trace elements and took part in this study. Rice samples were purchased and prepared by following a protocol that had been proposed for this study. Samples were analyzed by their own NAA

systems. In each country, more than 10 elements were examined and the results were compared. These data will be very useful in the monitoring of the levels of food contamination and to evaluate the nutritional status for people living in Asia.

**Keywords** White rice · Inorganic elements · Neutron activation analysis · Asian countries · Dietary intake level

### Introduction

The Forum for Nuclear Cooperation in Asia (FNCA) funded by the Japanese government was established to be recognized as an effective mechanism for enhancing socio-economic development through active regional partnership in the peaceful and safe utilization of nuclear technology in 2000. Collaborative studies applying neutron activation analysis (NAA) have been carried out as one of FNCA projects for applications of nuclear technology for socio-economic development [1, 2].

In the FNCA workshop held in Dalat, Vietnam in 2008, seven Asian countries, China, Indonesia, Japan, Korea, Malaysia, Philippines and Thailand, agreed to participate in a food sample analysis as a sub-theme of the NAA project. Rice was chosen as a common target sample due to its importance in terms of a staple food for people living in the Asian region. That is, the major rice production countries in Asia are China, India, Indonesia, Bangladesh, Thailand, etc., and they account for more than 80 percent of the world's rice production and consumption. It implies that rice provides important information of mineral supplement as well as a large portion of calories for Asians. As scientists have focused their research on health impacts caused by mineral nutrient deficiency and hazardous

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J. H. Moon (✉)  
Korea Atomic Energy Research Institute, Daeduck-Daero  
989-111, Duckjin-Dong, Yuseong, Daejeon, Korea  
e-mail: jhmoon1@kaeri.re.kr

M. Ebihara  
Department of Chemistry, Tokyo Metropolitan University,  
Hachioji, Tokyo 192-0397, Japan

B. F. Ni  
China Institute of Atomic Energy, Beijing, People's Republic of  
China

B. Arporn  
Thailand Institute of Nuclear Technology, Bangkok, Thailand

P. Setyo · R. M. Theresia  
National Nuclear Energy Agency, Serpong, Indonesia

B. S. Wee · N. A. Abd. Salim  
Malaysian Nuclear Agency, Bangi, 43000 Kajang,  
Selangor, Malaysia

P. C. B. Pabroa  
Philippine Nuclear Research Institute, Quezon City, Philippines

**Table 1** Process of sample collection of white rice and preparation for INAA

Country	Sampling and preparation as an analytical sample
China	Four different origin samples (Hebei, Sichuan, Yueyang, Liaoning) were purchased from a market in Beijing and were separately prepared as four individual samples
Indonesia	Two unknown origin samples were purchased markets in Jakarta and Banten and prepared as an analytical sample by mixing them
Japan	One known origin (Chiba) and two unknown origin samples were purchased from markets in Tokyo and were separately prepared as three individual samples
Korea	Three different origin samples (Ganghwa, Gimpo, Ichoen) were purchased from a market in Daejeon and prepared as an analytical sample by mixing them
Malaysia	Two different origin samples (peninsular Malaysia, Sabah) were purchased from markets in Peninsular Malaysia and were separately prepared as two individual samples
Philippines	Four different unknown origin samples were purchased from a market in Quezon City and were separately prepared as four individual samples
Thailand	Three unknown origin samples were purchased from three different markets in Bangkok and prepared as an analytical sample by mixing them

elements [3–5], public concerns about mineral intake by dietary food is rising worldwide.

The objectives of this study were to determine inorganic elemental contents in white rice of seven Asian countries by NAA and to assist the evaluation of rice in nutritional and toxic levels for the populations of these seven participating countries.

## Experimental

### Sampling and sample preparation

Rice sample collection and its preparation for INAA in each country are given in Table 1. The collected rice grains were cleaned once with tap water, twice with deionized (DI) water and then dried in a hot-air oven at 60 °C for 4 h. And then, the sample was ground into fine particles using a high-speed blender made of titanium to reduce contamination. The grinding step was repeated until fine particles passed completely through a No. 60 mesh sieve. Finally, three replicates with sample weights of 100–300 mg were prepared for instrumental neutron activation analysis (INAA).

### Instrumental neutron activation analysis

The samples prepared for INAA by each country, and certified reference materials for analytical quality control, were analyzed using their own NAA facilities excluding the Philippines, which used the same facility as Japan. Detailed information is summarized in Table 2. The samples were activated by short and long irradiation to detect short-, median- and long-lived nuclides. In order to detect the gamma-rays emitted from the irradiated samples, HPGe detectors coupled to multichannel analyzers were used. Consequently, the elemental content was determined by relative method and/or  $k_0$ -method.

## Results and discussion

### Inorganic elemental contents in white rice samples

Fifteen elements were determined by seven participating countries, and the results are summarized in Table 3. With respect to analytical quality control, various reference materials as described in Table 2 were analyzed, and the

**Table 2** NAA facilities and quality control materials

Country	Reactor name	Power	Thermal neutron flux	QC materials
China	MNSR, SPR	27 KW, 3.5 MW	$5 \times 10^{11}$ n/cm <sup>2</sup> s, $1 \times 10^{13}$ n/cm <sup>2</sup> s	NIST SRM 1632a-coal, GBW-10016-tea
Indonesia	GA. Sywabessi	30 MW	$3.5 \times 10^{13}$ n/cm <sup>2</sup> s	NIST SRM 1573a-tomato leaves, NIST SRM 1547-peach leaves, NIST SRM 8435-whole milk, NIST SRM 1577-bovine liver
Japan	JRR3M	20 MW	$\sim 3.0 \times 10^{14}$ n/cm <sup>2</sup> s	NIES 10b, 10C-rice flour
Korea	HANARO	30 MW	$3 \times 10^{13}$ n/cm <sup>2</sup> s	NIST SRM 1568a-rice flour
Malaysia	TRIGA Mark II	1 MW	$2 \times 10^{12}$ n/cm <sup>2</sup> s	NIST SRM 1573a-tomato leaf, NIST SRM 1568a-rice flour
Thailand	TRR-1/M1	1.2 MW	$1 \times 10^{11}$ n/cm <sup>2</sup> s	NIST SRM 1568a-rice flour

**Table 3** Analytical results of white rice from seven countries (Unit: mg/kg)

Element	<sup>a</sup> China	Indonesia	<sup>b</sup> Japan	Korea	<sup>c</sup> Malaysia	<sup>d</sup> Philippines	Thailand
Al	<4.46	<20.52	<1.66	<1.38	<2	<2.82	<2.33
As	0.55	0.08	0.10	0.13	0.11	0.07	0.09
Br	0.35	0.45	0.50	0.19	13.6	5.35	0.43
Ca	N.A	<4.53	49.5	53.9	<10	39.1	<15
Cl	264	210	239	193	225	236	239
Co	<0.3	0.77	N.A	0.005	0.026	N.A	0.022
Cr	0.25	0.38	N.A	<0.01	<0.08	N.A	<0.4
Cs	<0.07	0.09	N.A	0.009	0.016	N.A	N.A
Fe	N.A	4.65	N.A	1.58	<5	N.A	<16
K	977	739	611	660	573	637	620
Mg	379	131	149	241	<150	90	59
Mn	9.25	9.95	7.66	9.06	6.19	7.89	9.23
Na	10.3	7.7	5.69	4.10	13.7	5.17	4.58
Rb	<3.35	7.64	N.A	1.39	2.10	3.24	1.34
Zn	15.3	24.2	18.5	15.3	10.1	15.4	21.4

N.A not applicable

<sup>a</sup> Average values from four different origin samples

<sup>b</sup> Average values from one known origin sample and two unknown origin samples

<sup>c</sup> Average values from two different origin samples

<sup>d</sup> Average values from four unknown origin samples

results for fifteen elements are summarized in terms of relative error (%) with absolute values, which are shown in Fig. 1. The relative errors of most of the elements evaluated in Fig. 1 are within 15% except a few elements.

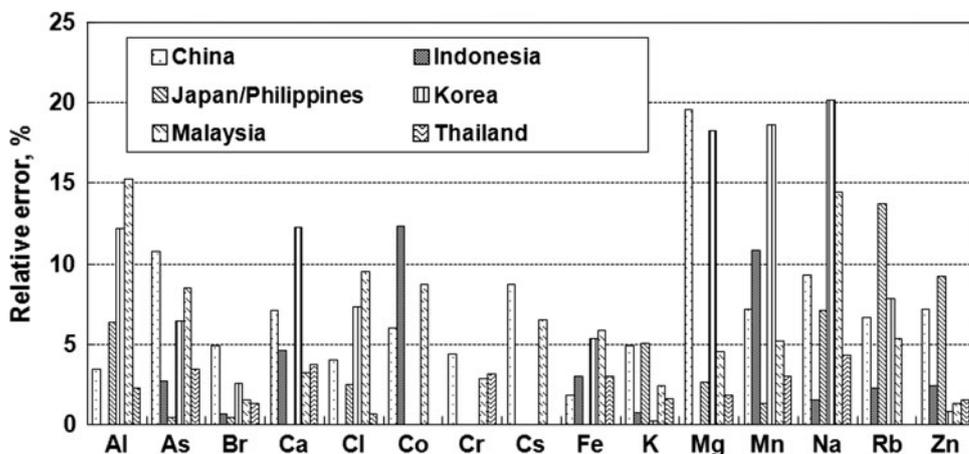
In Table 3, K results presented the highest values among the analyzed elements within a range of 573 to 977 mg/kg and following K are Cl and Mg. Seven elements such as As, Br, Cl, K, Mn, Na, and Zn were determined by all participating countries. China has the highest value of As, 0.55 mg/kg and the other countries show a similar As contents, approximately 0.1 mg/kg. For Br, Malaysia and Philippines have ten times the level of the other countries. For the other five elements, there is no significant difference and the mean concentration and their standard deviation for Cl, K, Mn, Na, and Zn were  $229 \pm 23$ ,  $688 \pm 137$ ,  $8.46 \pm 1.29$ ,  $7.31 \pm 3.52$  and  $17.2 \pm 4.6$  mg/kg, respectively. Al and Mg concentrations were determined from six countries excluding Malaysia. Indonesia

shows a remarkably high Al value, 20.52 mg/kg and Thailand has the lowest Mg content, 59 mg/kg. Ca data were provided from Japan, Korea and the Philippines which are 49.5, 53.9 and 39.1 mg/kg. Other countries show lower than 15 mg/kg of Ca. The concentrations for Cr, Cs, Fe, and Rb in Indonesian rice are much higher than those of other countries. Chinese rice presented the highest Mg content of 379 mg/kg.

Evaluation of dietary intake level for harmful and essential elements

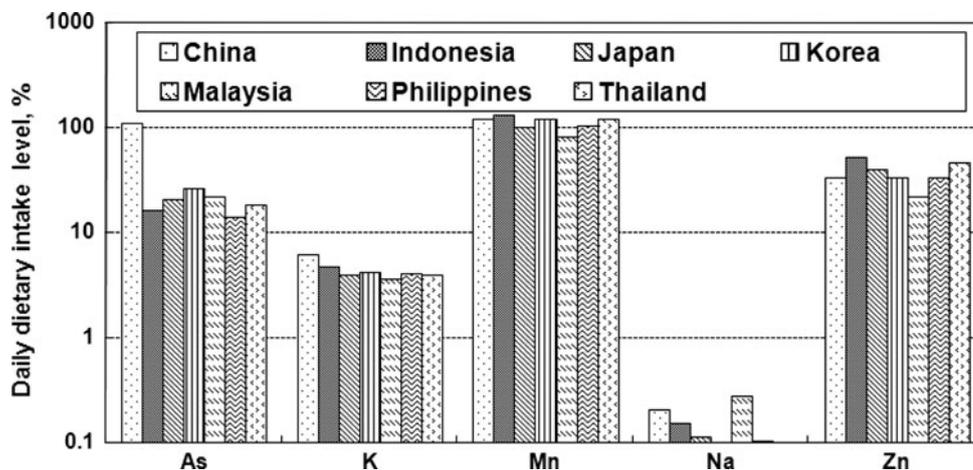
In order to estimate the dietary intake of inorganic constituents via white rice, a daily consumption survey is indispensable. For instance, the daily average consumption of rice in Korea in 2000 was 256 g (Ministry of Agricultural and Forestry of Korea, 2003) [6]. However, rice consumption must be dependent on each country's situation.

**Fig. 1** Absolute relative error (%) of analytical values with certified/reference values



**Table 4** Daily intake values for five elements via white rice

Element	China	Indonesia	Japan	Korea	Malaysia	Philippines	Thailand
As ( $\mu\text{g}$ )	165	24	31	39	33	21	27
K (mg)	293	222	183	198	172	191	186
Mn (mg)	2.78	2.99	2.30	2.72	1.86	2.37	2.77
Na (mg)	3.09	2.31	1.71	1.23	4.10	1.55	1.37
Zn (mg)	4.59	7.26	5.54	4.59	3.03	4.61	6.42

**Fig. 2** Evaluation of daily dietary intake level (%) for five elements via white rice

Hence, assuming that the average consumption of rice is 300 g/day for a comparison of daily intake levels among the seven countries, daily intake values can be simply calculated for five elements such as As, K, Mn, Na and Zn determined from all participating countries and known to be harmful or essential in human body, as shown in Table 4. In the mean time, the Joint Food and Agriculture Organization of the United Nations and the World Health Organization Expert Committee on Food Additives (JECFA) have set a recommended weekly safe exposure limit, which is 15  $\mu\text{g}/\text{kg}$  of body weight for inorganic As [7]. Assuming that the body weight of an adult is 70 kg, the daily safe exposure limit of As is equal to 150  $\mu\text{g}$ . In addition, the Institute of Medicine (IOM) in the United States has set the values of recommended dietary allowance (RDA) or adequate intake (AI) for essential elements [8–11]. RDA for Mn and Zn were set as 330 mg/day for adult men (19–30 years) and 14 mg/day for men, respectively. AI for K and Na set by IOM are 4.7 g/day for all adults and 1.5 g/day for young adults, respectively. Daily dietary levels (%) for five elements according to a safe limit, RDA and AI, was obtained and shown in Fig. 2. Dietary level (DL) of As in China surpasses the recommended safe exposure limits of JECFA and the others are within the safe limits. Although the Mn level is almost equal to the value of RDA, it is lower than the tolerable upper intake level value, 11 mg/day recommended by IOM. In case of Zn, the range of DL is 21.6–51.9%. The range of DL K is 3.7–6.2% of AI, and Na is lower than 0.3% of AI.

## Conclusion

A collaborative study for the analysis of white rice among seven Asian countries was carried out for applications of nuclear technology for socio-economic development. Fifteen elements from white rice samples were determined by INAA. The analytical data were compared between participating countries and daily dietary intake levels were evaluated in comparison with recommended dietary allowance and adequate intake values set by IOM. The current data showed no significant contamination of heavy metals in rice samples from participating countries. It is expected that FNCA will keep playing an important role in consolidating collaboration studies among Asian countries.

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