Original Article

Assessment of Fluoride Intake from Rice Consumption by Using Tap Water Containing Fluoride for Rice Soaking Water

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*Department of Urban Engineering, the University of Tokyo, Tokyo, Japan***ABSTRACT**

The people in Thailand generally soak sticky rice in water for 12–24 h before steaming and rinse jasmine rice before cooking. This study aimed at estimating fluoride intake from rice by the measuring rice consumption and examining factors affecting fluoride adsorption on jasmine rice and sticky rice in Buak Khang Subdistrict, Chiang Mai Province, Thailand. It was found that 65.7% of 35 households still use tap water containing fluoride at 5.94 ± 0.29 mg/L of fluoride for rice soaking and rinsing. The amount of jasmine rice and sticky rice consumption was 0.096 ± 0.05 kg/meal and 0.114 ± 0.06 kg/meal, respectively. The fluoride taken up into rice exhibited a positive correlation with the initial fluoride in water, the duration and water volume for rice soaking. The fluoride intake from jasmine rice and sticky rice based on the field survey was 0.004 ± 0.007 mg/kg-bw/day and 0.025 ± 0.024 mg/kg-bw/day, respectively. The results of this study indicated that eating rice can significantly contribute to the total amount of fluoride intake; thus, it is recommended to use fluoride-free water or reducing time duration for rice soaking in areas using fluoride-containing groundwaters.

Keywords: fluoride, groundwater, rice consumption, rice soaking water, tap water

INTRODUCTION

Fluoride has both beneficial and adverse effects on human health depending on its concentration in drinking water [1,2]. Fluoride can accumulate in teeth via ion exchange with hydroxyl groups of hydroxyapatite ($\text{Ca}_5(\text{PO}_4)_3\text{OH}$), forming fluorapatite ($\text{Ca}_5(\text{PO}_4)_3\text{F}$) [3]. Low levels of fluoride, e.g. 0.5 mg/L, is considered to prevent and/or reduce dental decay [4,5]. Besides, Adequate Intake (AI) of fluoride was established by the United States Institute of Medicine (IOM) in 1997 at 0.05 mg F/kg-bw/day [6]. Nevertheless, high fluoride concentrations above 1.5 mg/L in drinking water may cause several forms of fluorosis such as dental, skeletal, or non-skeletal fluorosis [7–9]. Dental fluorosis appears as white spots or mottling of enamel among children and young people [10–12]. Skeletal fluorosis is caused by chronic results in discomfort or pain of neck, bone and/or joint, and ultimately cause bone fracture and/or permanent disability in elderly people [13,14]. Thus, a large number of popula-

tions drinking groundwater that contains excess fluoride is a worldwide concern [15].

Fluoride in groundwater occurs mainly from the weathering and leaching of fluorine-bearing rocks, i.e. fluorite, fluorapatite, and biotite [16,17]. Fluoride could enter into human body through drinking water, food ingestion, inhalation and dermal absorption [18,19]. However, the main exposure pathway of fluoride has been considered to be drinking water consumption, comprising about 75% of the total fluoride intake [20]. Based on a water intake of 2 L per day for an average body weight of 60 kg, the guideline value of fluoride in drinking water was set at 1.5 mg/L by World Health Organization. However, water consumption is dependent on the climate of each area [21]. Thus, the ministry of Public Health in Thailand has set a standard of fluoride concentration in drinking water to be 0.7 mg/L [22].

Fluoride intake by an individual is dependent on the amounts of direct water consumption from drinking water, indirect water consumption from food including rice,

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and other beverages [23,24]. Although there are numerous papers published on fluoride intake from drinking water [25,26], there are only limited number of publications on fluoride intake from food as it is considered to be a minor source of fluoride intake. In most of the literature on food consumption, the amount of fluoride intake was reported by household survey [27], but the reported intake values vary significantly. Gupta *et al.* [28] employed the average amount of food consumption for fluoride intake estimation; namely, assuming 500 g of meal ingredient, 500 g of vegetable food and 5 L of water per day for adult, the average fluoride intake from paddy (rice) was reported to be 6.16 mg/capita/day. Other researchers obtained food consumption data by 24 hour-recording of food consumption by household members and reported 0.018 ± 0.008 mg/kg-bw/day as the daily fluoride intake from drinking water and food [29]. The average fluoride intake from solids was also reported to be 0.008 ± 0.005 mg/kg-bw/day [30]. The daily dietary fluoride intake based on 3-d food diary method or the 2-d duplicate plate method were reported to be 0.025 ± 0.016 mg/kg-bw/day and 0.028 ± 0.013 mg/kg-bw/day, respectively [31]. The total amount of fluoride intake was estimated at 0.071 ± 0.036 mg/kg-bw/day, including 0.025 ± 0.010 mg/kg-bw/day from diet and 0.046 ± 0.035 from toothpaste [32]. Abuhaloob *et al.* [33] reported that food was the largest contribution (63.9%) of total daily fluoride intake. However, fluoride intake from each food stuff, such as rice consumption, was not reported.

Rice is the staple food in many areas around the world, especially in Asia [34–37]. The rice texture depends on the starch structure that consists of two molecules: amylopectin and amylose [38,39]. The cooking method of rice including rice washing and soaking process affect rice texture [40–42]. Rice grains absorb water and swell after soaking in water, then the structure of rice is loosened to be testier [43].

Tegegne *et al.* [44] reported that the fluoride can be adsorbed into rice from water during cooking, fluoride in rice increased with the increasing fluoride concentration in cooking water. Viswanathan *et al.* [27] estimated the fluoride contents in cooked rice assuming that dissolved fluoride ions in cooking water was adsorbed in rice grain. However, the amounts of water taken up into rice could be dependent on the types of rice and the rice cooking methods, such as rice soaking and rice rinsing. Thus, in order to estimate fluoride intake from rice consumption, it is necessary to assess the actual cooking methods of rice including rice soaking, and the amounts of rice consumption.

Sticky rice is the main source of rice consumption in the northern part of Thailand. The processes for sticky rice

cooking are soaking, rinsing and steaming with tap water. It was reported that the fluoride concentration in tap water in Buak Khang Subdistrict area, San Kamphaeng District, located in Chiang Mai basin was between 0.75 and 7.46 mg/L [45]. Groundwater is the main source to produce tap water. The sticky rice was soaked in water in order to improve the texture of cooked rice. Then, soaked rice was rinsed for cleaning before steaming. Because the main source of water for rice soaking and rinsing is tap water, it is likely that fluoride is taken up into rice in these processes if tap water containing fluoride.

Therefore, the residents in Chiang Mai, Lamphun, Mae Hong Son provinces, located in the northern part of Thailand, had been suffering from fluorosis caused by drinking fluoride-laden groundwater [46,47]. Bottled water produced in the reverse-osmosis plant in the local area is a preferred source of drinking water in Buak Khang area; however, there are still households using tap water containing high fluoride concentration for cooking and rice soaking. Thus, eating rice cooked by the aforementioned methods could be a possible source of fluoride intake.

The objective of this study was to find the amounts of the fluoride intake from jasmine rice (JR) and sticky rice (SR) that are commonly consumed by the residents in Buak Khang area and to find the relationship between their cooking methods, namely rice soaking, and fluoride contents in rice. Thus, the amounts of rice consumption per meal was measured; the cooked and uncooked rice samples were obtained from households to analyze their fluoride contents; and their fluoride intake from rice was reported as a function of their age, body weight and sex. To assess the effects of cooking process on fluoride adsorption on rice, the processes of cooking jasmine rice and sticky rice were observed in the field survey. Laboratory experiments were also conducted to analyze the factors affecting fluoride adsorption on rice, namely, fluoride concentration in water, time duration for soaking and the ratio of water volume to rice for soaking, and the results were compared with the fluoride contents of rice obtained by the field sampling.

MATERIALS AND METHODS

Survey area

The study area, Buak Khang Subdistrict, San Kamphaeng District, Chiang Mai Province, Thailand, is located in the northern part of Thailand (**Fig. 1** insert map). The population of Buak Khang Sub-District was 8,059 and it consisted of 13 villages. This study selected two villages, with populations

Fig. 1 Flow diagram of village waterworks in Chiang Mai (Location of the study area: top-left side).

of 1,001 and 577, for the water sampling and consumption surveys because their groundwaters have fluoride concentrations higher than 0.7 mg/L [45].

The residents in the Buak Khang area have used tap water (TW) from the village waterworks (VWW) that took sources from groundwater (GW) (Fig. 1). In the water treatment plants, GW is abstracted by a submersible pump, and then aerated by showering on to the aeration trays to oxidize and remove iron and manganese [48]. Treated water is stored in a storage tank and chloride is added for disinfection. The treated water is then pumped up to the elevated distribution tank by using a centrifugal pump. The water is distributed from the elevated distribution tank to each household. Thus, there is no fluoride-removal process in the treatment plant.

The residents use treated water from RO plants is packaged in 1-L and 20-L PET bottles for drinking and cooking.

Sample selection and questionnaire survey

In the study area, 35 households with 71 female and 52 male subjects were randomly selected for questionnaire and rice consumption survey. The survey methods in this study followed the guidelines for a research on human subjects

of the Graduate School of Engineering, the University of Tokyo, Tokyo, Japan, comply with relevant regulations, and were approved of by the Research Ethics Committee, Graduate School of Engineering, the University of Tokyo, the objective and methods were explained to the subjects before the questionnaire survey was conducted and only those who consented to participate in the survey were selected as subjects

The survey was conducted between February 23, 2018 and March 19, 2018, during which time the average ambient temperature was 26°C (18.0–38.0°C).

Before the survey, the objectives of this survey were explained to the subjects and the questionnaire sheet written in Thai was delivered to a member of the household (Supplementary Material). In this questionnaire survey, number of household members, water sources for drinking, cooking, and rice soaking in their daily life, and the rice soaking conditions were asked. In addition, the body weight of each subject was measuring by a digital weighting scale. The results obtained from field survey and questionnaire data were used to estimate the effects of age, body weight, and sex on rice consumption and fluoride intake.

Rice consumption survey

From the 35 households, bottled water, tap water and rice samples were collected. Only rice was assumed to be the source of fluoride intake because it was rinsed and soaked with tap water containing high fluoride concentration. Although the subjects in this study consumed rice and other types of food, consumption of JR and SR per meal was directly measured in the field survey. The cooked JR and SR were prepared and brought to the survey, and the subjects were requested to scoop a portion of rice that they usually eat in one meal into the bowl. Then, the amount of rice was measured by a digital weighting scale and was recorded. Besides, the ratios of water and rice for cooking and soaking before steaming with tap water were directly measured by a weighting scale. Among the total subjects of 123 people, those did not eat JR and/or SR at all, i.e. zero consumer, were excluded from the calculation, the details of this calculation method were added in the text.

Analysis of fluoride in water and rice

The fluoride concentrations of the tap water and bottled water samples were analyzed using a fluoride-sensitive electrode (ORION STAR A324, Thermo Scientific, Waltham, USA). Ten samples of cooked JR and 23 samples of cooked SR were collected from households. JR is cooked by firstly rinsing with tap water containing fluoride, then cooking by a rice cooker using bottled water, which had no effect on fluoride contents in rice. SR was cooked by soaking in tap water, then steaming by tap water. However, steaming process was not considered as a cause of fluoride adsorption in rice because fluoride dose not evaporate from water. No effects of rice cooking by a rice cooker and rice steaming on fluoride contents in rice were confirmed in the preliminary experiments. Due to these reasons, rice rinsing and rice soaking were assumed to be the main source of fluoride into rice, and the changes of fluoride contents by rice rinsing or soaking were assumed to be the same as those of cooked or steamed rice. Fluoride contents in rice samples were measured according to the Association of Official Analytical Chemists (AOAC) official method by using the fluoride-sensitive electrode (ORION STAR A324). Firstly, rice samples were dried for 48 hours in an oven at 80°C. Secondly, 0.5 g of rice sample was prepared into a 50 mL of a plastic bottle. Then, 20 mL of 0.05 mol/L HNO₃ was added and stirred by a magnetic stirrer for 20 min; 20 mL of 0.1 mol/L KOH was added and stirred by a magnetic stirrer for 20 min; and 5 mL of 0.2 mol/L HNO₃ was added. Finally, the TISAB-II buffer was added to adjust pH and ionic strength before fluoride

content was measured by the fluoride-selective electrode.

Rice soaking experiments

The factors, namely, fluoride concentration in water, time duration for soaking, and the water-to-rice ratio for soaking were varied in the fluoride adsorption experiments in the laboratory. The initial fluoride concentration in soaking water was varied between 1 mg/L and 20 mg/L, the water-to-rice ratios were varied from 1.3 kg/kg to 4.0 kg/kg and the soaking time duration was varied from 1 to 24 h. The water-to-rice ratio was set based on the obtained values that was directly measured in the field survey. Then, the fluoride contents in rice samples were analyzed following the AOAC official method. Although JR was not soaked in practice before cooking, soaking experiments on JR, as well as SR, were conducted in order to estimate the fluoride adsorption potential on JR. The effect of shaking in rice soaking experiments was evaluated before these soaking experiments. It found that fluoride content on soaked rice had no significant difference between rice soaking with and without shaking ($p > 0.05$). Thus, all the rice soaking experiments were conducted without shaking, which were the same with the actual procedure of rice soaking.

Fluoride intake estimation

The fluoride intakes from drinking water and cooking water were estimated by multiplying fluoride concentration of bottled water or tap water with the volume of drinking and cooking water consumption, as reported in our previous publication [49]. The cooking water in our study did not included rice rinsing water, rice soaking water, rice cooking water and dish washing water. The amounts of fluoride intake per body weight from rice consumption (mg/kg-bw/day) was estimated based on fluoride contents in rice obtained by the field sampling, and the amount of rice consumption per meal following equation (1). The amounts of rice consumption (kg) were directly measured as cooked (wet) rice; however, the fluoride contents in rice was measured on the dry weight of rice. Thus, the rice consumption on dry basis in equation (2) and (3) was calculated from wet weight from the field using the water content values in rice that obtained from soaking experiments (Fig. S1).

$$F_R = \frac{R_I \times C_R}{B_w} \quad (1)$$

F_R : the fluoride intake from rice (mg/kg-bw/day)

B_w : body weight (kg)

C_R : fluoride concentration in rice (mg/kg-rice)
 R_f : rice consumption on dry-weight basis (kg/day), calculated by equation (2).

$$R_f = \frac{R_{m,d} \times f_m \times f_d}{7(\text{day / week})} \quad (2)$$

$R_{m,d}$: rice consumption per meal on dry-weight basis (kg/meal)

f_m : number of meals for rice consumption in one day (meal/day)

f_d : number of days for rice consumption in one week (day/week)

$$R_{m,d} = R_{m,w} - \text{g of water} \quad (3)$$

$R_{m,w}$: rice consumption per meal on wet-weight basis (kg/meal)

$$\text{Water content} = \frac{\text{kg of water}}{R_{m,w}} \quad (4)$$

Water content: 0.424 for jasmine rice and 0.464 for sticky rice

Statistical analyses

The statistical analyses were conducted in R v.3.2.3 (R Core Team, Vienna, Austria) and the results were considered significant at $p < 0.05$ level.

RESULTS AND DISCUSSION

Fluoride in tap water and RO treated water

The VWW tap water contained fluoride at 5.94 ± 0.29 mg/L, and 65.7% of households used VWW tap water for rice cooking including soaking and rinsing. The fluoride concentration in bottled water ($n = 35$) produced in the local RO plant in Buak Khang Subdistrict was 0.07 ± 0.05 mg/L. This result implies that the local RO treatment plant was effective in removal of fluoride from tap water to meet the guideline value for drinking water in Thailand (0.7 mg/L). However, because tap water from the local people in Buak Khang Subdistrict use tap water for rice cooking.

JR and SR cooking methods

It was found by the interview survey that the people in our study area generally soak SR in water (**Fig. 2a**) for 12–24 h before steaming with tap water (**Fig. 2b**) in order to get

Fig. 2 Process of sticky rice steaming:

(a) Soaking process (b) Steaming process.

the soft and delicious cooked rice. Contrarily, JR was rinsed with water for 2–3 times to clean it before cooking by a rice cooker. The water to rice ratios for JR cooking and SR soaking in the study area were 2:1 for JR cooking and 2:1–4:1 for SR soaking. Tap water was the main water source selected for rice soaking and rinsing because the local people consider that it is safe as water is poured out before being cooked.

Rice consumption

Among the total number of 71 females and 52 males, 26 female and 23 males did not consume JR (zero JR consumption), and 6 female and 5 males did not consume SR (zero SR consumption). SR was the preferred type of rice for eating at household in Buak Khang Subdistrict. The subjects consumed JR 2.66 ± 2.23 days/week and 1.31 ± 1.06 meals/day, SR 6.51 ± 1.25 days/week and 2.83 ± 0.65 meals/day. 73.3% of households reported that they consume SR 3 meals for 7 days.

The local people in Buak Khang area consume at 0.096 ± 0.05 kg/meal of JR and 0.114 ± 0.06 kg/meal of SR. Among total subjects of 123 people, those did not consume JR and/or SR, i.e. zero consumption, were excluded from the calculation of the mean rice consumption. The rice consumption was normalized as kg of rice per capita per day then, using equations (1) and (2). Although the consumption frequency data only obtained from questionnaire data of each household, the rice consumption frequency of each subject was assumed the same number of each household. **Figure 3** illustrates the comparative amount of JR and SR consumption. 82.1% of subjects, consisting of 57 female and 44 of male subjects prefer to eat SR more than JR ($\text{SR}/\text{JR} > 1$). Furthermore, 73.2% of subjects consume SR more than

Fig. 3 Relationship between jasmine rice consumption and sticky rice consumption ($n = 123$).

twice of JR. A previous research reported that the amount of rice consumption in Thailand was 0.285 kg/day [50]. In this study, only one subject out of 123 subjects ate JR more than 0.285 kg/day; however, 40.7% consumed SR more than 0.285 kg/day. Besides, the United Nations World Food Programme reported the rice consumption in countries where rice is a staple food was 0.4 kg/day on average [51]. However, 23.6% of SR consumer consumed more than 0.4 kg/day in this study. Furthermore, in terms of the total rice consumption (JR plus SR), 35 subjects in this study consume higher than 0.4 kg/day.

Rice consumption of male and female subjects

The median JR consumption of male subjects (0.105 kg/capita/meal) was significantly higher than that of female subjects (0.074 kg/capita/meal) (t -test, $p < 0.05$) as shown in Fig. 4a. Figure 4b shows the difference in SR consumption between male and female subjects. The median SR consumption of male subjects (0.126 kg/capita/meal) was significantly

higher than that of female (0.091 kg/capita/meal) (t -test, $p < 0.05$). The amount of SR consumption by the male was 1.38 times more than that by the female, which was in agreement with the reported value of 1.3 by Hensawang *et al.* [52]. Thus, this indicates that the male subjects were likely to take higher amounts of fluoride from rice consumption than the female.

Body weight and rice consumption

Most of the subjects had bodyweights in a range of 40 kg to 80 kg. Figure S3 shows widely scattered plots of the relationship between the body weights and rice consumption. Three males consumed the maximum amount of JR (0.29 ± 0.01 kg/capita/meal); however, their body weight was significantly different between each other. The regression by generalized linear models (GLMs) indicated that JR and SR consumption per capita by both of female and male subjects did not significantly increase with their body weight ($p > 0.05$). 32.5% of the subjects ate JR more than 0.1 kg/meal of rice, of whom 47.5% weighed less than 60 kg including three

Fig. 4 Jasmine rice (JR) consumption and sticky rice (SR) consumption of male and female subjects: (a) JR (kg/capita/meal), (b) SR (kg/capita/meal).

children (9–14 years old). Among 44.7% of the subjects who ate SR more than 0.1 kg/meal, 58.1% were male, 43.6% had body weights less than 60 kg, and four of them were children (4–14 years old). While the heavy-weight subjects consumed larger amount of rice than the low-weight subjects, they consumed less amount of rice than the low-weight subjects in terms of rice consumption per kilogram of body weight (kg/kg-bw/day) as shown by the negative slope of the regression lines in **Fig. 5**. In addition, although the amount of SR consumption by male was higher than that by female, the JR consumption by male in terms of kg/kg-bw/day was not significantly higher than that of female ($p > 0.05$) due to higher male's body weight (**Fig. S4**) at the same rice consumption (kg/capita/day). Based on the results of this study, it was suggested that the low-weight subjects, especially children are at a higher risk of fluorosis due to higher possibility fluoride intake per body weight than the heavy-weight subjects [8,9].

Age and rice consumption

The relationship between subject's age and rice consumption is illustrated in **Figs. S5** and **S6**. The subject's age did not a big effect on JR consumption ($p > 0.05$, GLM). The consumption of JR and SR by female showed stable trends with their ages, but the of rice consumption by male decreased with their age.

In this study, the body weights of the male subjects

continuously increased with their ages up to 40 years old. However, the body weights of the female subjects were stable between 20 and 60 years. The children (age 0–20 years) and elderly subjects (> 60 years) in this study had lower body weights than the intermediate age groups (20–60 years) (**Fig. S2**). Therefore, when subjects of different ages consumed the same amount of rice, children and elderly subjects tend to consume more rice than the other subjects in terms of rice consumption per kilogram of body weight. However, the amount of rice consumption by elderly subject in this study was less (**Fig. S5**). Thus, the children consume high amount of rice in terms of rice per body weight (**Fig. S6**), and they are identified to be a high fluorosis-risk group.

Effects of fluoride concentration and soaking water-to-rice ratios on fluoride adsorption on rice

The fluoride content in raw rice was measured as 0.48 ± 0.07 mg/kg and 0.41 ± 0.19 mg/kg in raw JR and raw SR, respectively. It implies that the initial fluoride content in raw rice had no influence on the fluoride content in rice after soaking in fluoride containing water. The fluoride contents in rice increased with fluoride concentration in soaking water (**Fig. 6**). When the water-to-rice ratio was reduced from 4 kg/kg to 1.3 kg/kg with 24 h-soaking, the fluoride content in rice slightly decreased [47]. If a water-to-rice ratio of 1.3 was used for rice soaking instead of 4, the fluoride contents in JR

Fig. 5 Relationship between body weight and rice consumption per body weight: (a) JR, and (b) SR ($n = 123$).

Fig. 6 Fluoride concentration in soaking water and fluoride in rice at various water-rice ratios and soaking time

(a) JR and (b) SR

Soaking time for the varied water-rice ratio experiments was 24 hours. The fluoride contents of the field samples were also plotted.

could be reduced by 26.3% and 56.3% using soaking water containing 5 mg/L and 20 mg/L of the initial fluoride concentration, respectively. Furthermore, the fluoride content in SR could be reduced by 44.2% when the water-to-rice ratio for soaking was reduced from 4 to 1.3 kg/kg at the initial fluoride concentration of 5 mg/L, or by 49.4% at 20 mg/L.

The fluoride contents in rice decreased with shorter soaking time duration (**Fig. 6**). When the soaking time was reduced from 24 to 12 h, and then to 1 hour, the fluoride content in JR was reduced by 3.60% and 39.8%, respectively, by using soaking water containing 5 mg/L of the initial fluoride. Similarly, fluoride contents in SR was reduced by 8.37% and 46.0%, respectively. These results of fluoride adsorption experiments showed that JR and SR can take fluoride ions during the soaking process. Thus, SR might be an important source of fluoride intake. By reducing rice soaking time, fluoride contents in rice could be significantly reduced.

The rice soaking with fluoride containing water was conducted in the laboratory experiment. However, the amount of fluoride content in cooked rice from field survey was compared with that in soaked rice from laboratory scale because rice rinsing which means that rice was soaked at short time and soaking process was considered as the source of fluoride absorption/adsorption into rice. The fluoride contents in the field rice samples were less than those in the lab experiments although they were relatively scattered (**Fig. 6**). The fluoride contents in JR was less than the regression line of the soaking duration of 1 h, except one sample, because JR was just rinsed before cooking (**Fig. 6a**). Most of the SR samples were plotted between soaking time of 1 h and 12 h, while some samples were below 1 h, which indicated their soaking duration was less than 1 h.

Estimation of actual fluoride intake from rice consumption

Figure 7 shows fluoride intake from JR and SR based on the number of rice meals that they eat per day. The guideline values are also drawn for reference. The reference dose (RfD) of fluoride intake set by the United States Environmental Protection Agency (US-EPA) is 0.06 mg/kg-bw/day, which consist of 0.05 mg/kg-bw/day through drinking water and 0.01 mg/kg-bw/day from dietary intake [53], which is plotted in **Fig. 7**. The average fluoride intake from any source of dietary including drinking water and food was established at 0.05 mg/kg-bw/day as fluoride reference values for Australia and New Zealand [54]. This is the same amount of the fluoride intake calculated from the World Health Organization (WHO) fluoride guideline value for drinking water

(1.5 mg/L) [55] based on a water consumption of 2 L/day and a body weight of 60 kg.

This means that, even if they use bottled water with very low fluoride concentration for drinking and cooking, they intake in excess amount of fluoride than the Nutrient Reference Vales for Australia and New Zealand, and the WHO guideline value of drinking water. The amount of fluoride intake from SR consumption was higher than that from JR consumption because SR contained fluoride higher JR. The high fluoride content in SR was related with SR soaking process before steaming.

The fluoride intake from rice samples in this study is shown in comparison with those from food in the previous studies that reported the amount of fluoride intake from solid food mixture including rice (**Table 1**). They estimated fluoride in food based on fluoride concentration in water, while, in this study, fluoride contents in rice was measured for the rice samples collected in the study area. There is no reference reporting fluoride intake only from rice consumption, but they estimated fluoride intake from a mixture of all type of solid food including rice. Although the types of food, the methods for estimation of fluoride intake and the fluoride concentration in water were different between the references shown in **Table 1** and this study, the fluoride intake from SR was comparable to the values reported in the references, but the fluoride intake from JR less than those values [33].

If subjects eat rice only one meal per day, only one subject intake fluoride over 0.01 mg/kg-bw/day from JR, while 29.7% of the subjects, consisting of female 40.9% and male 59.1%, intake fluoride over 0.01 mg/kg-bw/day for SR. However, in the actual situation found by the questionnaire survey, they ate rice, especially SR, more than one meal per day. 73.3% of the households reported that they consume SR 3 meals per day. Assuming three meals of rice consumption, 40% of the subjects who consume JR and 75.7% of the subjects who consume SR intake fluoride more than the US-EPA guideline value for fluoride intake from food (0.01 mg/kg-bw/day). Furthermore, 6.76% of the subjects who consume SR will intake fluoride more than 0.05 mg/kg-bw/day.

In addition, the fluoride intake (mg/kg-bw/day) by children subject was high (**Fig. S7**) because they have less body weight than other subjects (**Fig. S8**). Thus, the children consume high amount of rice in terms of rice per body weight. It implies that children are a high fluorosis-risk group. However, the fluoride content in rice is the one of factors that effect on the amount of fluoride intake (the outliers in **Fig. S7a** and **Fig. S7a**).

In order to compare the fluoride intake from different

Fig. 7 Estimated fluoride intake from rice meals based on fluoride contents in rice in the field samples (a) JR (b) SR.

Table 1 Fluoride intake from food.

Food samples	Fluoride concentration in water (mg/L)	A fluoride intake (mg/kg-bw/day)	Reference
Jasmine rice	5.94 ± 0.29	0.004 ± 0.007	This study
Sticky rice	5.94 ± 0.29	0.025 ± 0.024	
Solid food mixture including rice	0.21 ± 0.15	0.020 ± 0.010	[33]
	0.91 ± 0.13	0.040 ± 0.010	
	1.71 ± 0.35	0.050 ± 0.030	
	0.64	0.025 ± 0.010	[32]
Based on the group of foods		0.008 ± 0.005	[30]
		0.009 ± 0.004	[55]

Table 2 Fluoride intake from different sources.

Fluoride intake source	Water source:		
	1. Drinking water and cooking water, 2. Rice soaking and rinsing water		
	1. VWW tap water 2. VWW tap water	1. Bottled water* 2. VWW tap water	1. Bottled water 2. Bottled water
Drinking water (DW)	9.50 ± 5.29	0.19 ± 0.40	0.19 ± 0.40
Cooking water (CW)	5.55 ± 3.52	0.07 ± 0.05	0.07 ± 0.05
Jasmine rice	0.26 ± 0.40	0.26 ± 0.40	$0.0002 \pm 0.0002^{**}$
Sticky rice	1.29 ± 0.93	1.29 ± 0.93	$0.04 \pm 0.10^{**}$
Total	6.33 ± 5.14	0.34 ± 0.64	0.10 ± 0.25

The fluoride intake (mg/capita/day)

*Actual situation in the study area; DW and CW were bottled water, while rice soaking water was VWW tap water.

**Estimated base on the lab experiments.

sources, the unit of fluoride intake was normalized to the unit of mg/capita/day. The fluoride intake was estimated based on the fluoride concentration VWW tap water (5.94 ± 0.29 mg/L) or bottled water (0.07 ± 0.05 mg/L) of each house. **Table 2** shows that fluoride intake from drinking or tap water was 9.50 mg/capita/day. However, the sum fluoride intake from cooking and rice consumption was compared to the amount of fluoride intake from drinking water if the VWW tap water was used for cooking or rice soaking. It means that estimating fluoride intake only from drinking water underestimate the total amount of fluoride intake in the area where people mainly consume rice. Furthermore, in the actual case, rice is the main intake source of fluoride as the residents use bottled water for drinking and cooking, but not for rice soaking or rinsing. Therefore, to minimize fluoride intake, it is suggested for the residents that they used bottled water for rice soaking and rinsing; they soak rice in less than 1 hour with less amount of water, and they diversity their dietary, especially from SR.

CONCLUSIONS

The actual JR and SR consumption were quantified in Buak Khang Subdistrict, Thailand, where the local people have used tap water sourced that containing high fluoride concentration for rinsing and soaking rice in order to estimate the actual fluoride intake from rice consumption. The factors, namely, fluoride concentration in water, soaking time duration, water and rice ratio for soaking were also varied in laboratory experiments to investigate the possible fluoride intake. The average JR and SR consumption per capita per meal were 0.096 ± 0.05 kg/meal and 0.114 ± 0.06 kg/meal, respectively. The JR and SR consumption by male were significantly higher than that by female. The subject's age had no significant effect on rice consumption per capita per day. Body weight was the main factor affecting rice consumption. Low body-weight subject, especially children were found to consume more rice in terms of per kilogram of body weight per day, and thus were considered to be a high risk group for fluoride intake. JR and SR have high potential to adsorb fluoride during soaking and rinsing in the fluoride contain-

ing water. Fluoride concentration in water, time duration for soaking and water-to-rice ratio had effect on fluoride adsorption on JR and SR. The source of fluoride intake not only from drinking water consumption but also cooking and rice soaking water consumption should be considered to estimate the total fluoride intake. The possible way for fluoride intake reduction is using bottled water for all of rice cooking and soaking, otherwise reduce the water-to-rice ratio and soaking time and diversity SR to other food stuffs.

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SUPPLEMENTARY MATERIALS

Supplementary Materials file for this article is available at the link below.

https://www.jstage.jst.go.jp/article/jwet/18/2/18_19-084/supplement/_download/18_18-084_1.pdf

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