Role of Rice in Dietary Cadmium Intake of Farming Population with No Known Man-Made Pollution in Japan

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WATANABE, T., KOIZUMI, A., FUJITA, H., KUMAI, M. and IKEDA, M. *Role of Rice in Dietary Cadmium Intake of Farming Population with No Known Man-Made Pollution in Japan.* Tohoku J. exp. Med., 1984, **144** (1), 83-90 — The 24-hr duplicates of a whole day diet were collected in winter seasons from 1042 farmers in 49 non-polluted regions in Japan, and the amount of boiled rice in each duplicate was compared with the cadmium content in the duplicate to evaluate the role of rice in daily cadmium intake via food. The daily boiled rice intake (in terms of regional geometric means) varied in the range of 720-1,100 g/day for males and 300-800 g/day for females, yet positively correlated with whole day dietary cadmium intake in males ($0.07 < p < 0.08$), in females ($p < 0.01$) and the combination of the two sexes ($p < 0.01$). The findings, in accordance with other reports, suggest that rice is an important source of cadmium intake among Japanese population even in non-polluted areas. The roles of *sake* (rice wine) and beer appeared to be quite minor as the cadmium contents were very low. ——— beer ; cadmium ; diet ; rice ; rice wine

It has been generally considered that the rice (usually boiled to serve), the major source of energy in traditional Japanese diet (Organisation for Economic Co-operation and Development 1981), is also the leading source of cadmium for Japanese population under environmental cadmium pollution (Nogawa et al. 1978 ; Nogawa and Ishizaki 1979 ; Shigematsu et al. 1979). Analysis was made in the present study to examine whether or not such is also the case among the population with no known man-made cadmium pollution. Considerations were further extended to weigh the role of *sake* (rice wine) and beer as possible sources in cadmium intake.

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MATERIALS AND METHODS

Total diet collection

The 24-hr duplicates of a whole day diet (Yamagata and Iwashima 1975; Acheson et al. 1980) were collected in winter, 1977 to 1981, from 1042 adult volunteers (368 males and 674 females, mostly farmers) in 49 areas with no known man-made pollution in Japan, the locations of which were as previously reported (Watanabe et al. 1983). Additional samples were collected from some (209 subjects; 109 males and 100 females) of the same volunteers in immediately adjacent summers. Attentions were paid to ensure that typical daily diets be collected (Watanabe et al. 1984). While the collection included all the food and beverages as much as taken by each examinee, the examinees were specifically asked to store rice in a separate plastic box in order that the weight of rice could be recorded apart from other food and beverages.

Cadmium levels in total diet

Data were cited from a previous report (Watanabe et al. 1984); the determinations were based on the wet digestion of total diet homogenate followed by automated flameless atomic absorption spectrophotometry for cadmium (Watanabe et al. 1982).

Cadmium levels in alcoholic beverages

Analyses were conducted as previously described (Watanabe et al. 1982), taking the liquid samples in the place of the diet homogenates.

Statistical analysis

A preliminary analysis revealed that the amounts of boiled rice taken daily by the examinees of the same decade of age distributed log-normally. Accordingly, a log-normal distribution was assumed for boiled rice intake throughout the present study, so that the intake on group basis was expressed in terms of a geometric mean (GM), a geometric standard deviation (GSD) in parentheses followed by number of samples (N) [i.e., GM (GSD): N], unless otherwise specified. Dietary intake of cadmium also distributed log-normally (Watanabe et al. 1983).

RESULTS

Boiled rice intake by region and by sex

The GM's of daily intake of boiled rice varied in the range of 720–1,100 g/day for males and 300–800 g/day for females depending on the regions (Table 1). There was, however, no geographically biased distribution such as north-south difference.

When a comparison was made between the two sets of GM's for males and females in the regions where 3 or more samples were available for each sex, a significant ($p < 0.01$ by paired t test) difference in boiled rice intake was observed between the two sexes. Correlation between male values and female values was also significant ($p < 0.01$) with a regression line and a correlation coefficient of

$$Y = 319 + 0.803X \quad (r = 0.538, N = 20)$$

where Y and X are GM's (g/day) of boiled rice intake for males and females, respectively. The equation means that males take about 1.3 times more boiled rice than females in a region where females take 600–650 g boiled rice daily.

TABLE 1. *Daily boiled rice intake in winter in various regions*

District number ^a	Prefecture	Region number ^a	Boiled rice intake	
			Males	Females
			GM ^b (GSD) : <i>N</i>	GM ^b (GSD) : <i>N</i>
10	Hokkaido	4	754(1.35) : 41	627(1.54) : 18
	<i>ibid.</i>	5	726 : 1 ^c	582(1.33) : 18
9	Aomori	3	— ^d	525(1.42) : 15
	Miyagi	35	801(1.48) : 8	549(1.35) : 12
	<i>ibid.</i>	36	—	473(1.93) : 12
	<i>ibid.</i>	37	1107(1.27) : 8	467 : 1 ^c
	<i>ibid.</i>	38	797(1.45) : 17	794(1.27) : 17
	<i>ibid.</i>	39	—	300(1.50) : 20
	<i>ibid.</i>	40	818(1.52) : 10	—
	<i>ibid.</i>	41	925(1.47) : 7	573(1.40) : 7
	<i>ibid.</i>	42	706(1.46) : 13	667(1.32) : 5
	<i>ibid.</i>	43	—	581(1.33) : 16
	<i>ibid.</i>	44	—	605(1.60) : 40
	<i>ibid.</i>	45	888,471 : 2	542(1.39) : 17
	<i>ibid.</i>	46	917(1.50) : 9	793(1.28) : 14
	<i>ibid.</i>	47	—	597(1.45) : 39
	<i>ibid.</i>	48	742(1.45) : 9	—
	<i>ibid.</i>	50	981(1.20) : 9	—
	<i>ibid.</i>	51	913(1.32) : 11	—
	<i>ibid.</i>	52	1128(1.28) : 10	—
	<i>ibid.</i>	53	950(1.56) : 3	665(1.39) : 16
	<i>ibid.</i>	54	—	677(1.46) : 14
8	Fukushima	34	746(1.46) : 17	683(1.40) : 6
	Tokyo	6	—	323(1.68) : 24
	Saitama	7	—	585(1.42) : 28
	Gunma	8	—	498(1.30) : 19
	<i>ibid.</i>	9	—	665(1.25) : 20
7	Ishikawa	30	—	573(1.61) : 19
	<i>ibid.</i>	31	874(1.35) : 9	718(1.26) : 9
	Toyama	32	1247(1.13) : 5	743(1.27) : 16
	Niigata	33	987(1.32) : 5	553(1.48) : 18
6	Nagano	10	—	591(1.38) : 20
	Aichi	11	903(1.32) : 19	—
5	Wakayama	13	1149(1.44) : 40	—
	<i>ibid.</i>	14	713(1.54) : 11	574(1.35) : 16
4	Kagawa	18	—	588(1.50) : 21
	<i>ibid.</i>	19	672(1.74) : 17	623(1.54) : 5
	Kochi	20	1055(1.25) : 7	754(1.26) : 17

(continued)

District number ^a	Prefecture	Region number ^a	Boiled rice intake	
			Males	Females
			GM ^b (GSD) : <i>N</i>	GM ^b (GSD) : <i>N</i>
3	Ehimé	21	1100,691 : 2 ^c	666(1.23) : 20
	Shimané	15	—	804(1.33) : 20
	Yamaguchi	16	977(1.33) : 17	784(1.31) : 4
2	<i>ibid.</i>	17	997(1.38) : 20	—
	Fukuoka	22	—	714(1.35) : 26
	Kagoshima	24	557(1.69) : 4	540(1.39) : 19
	<i>ibid.</i>	25	813(1.01) : 5	682(1.35) : 26
	<i>ibid.</i>	26	—	690(1.21) : 19
1	Okinawa	27	691(1.41) : 10	536(1.33) : 11
	<i>ibid.</i>	28	617(1.21) : 10	412(1.35) : 10
	<i>ibid.</i>	29	809(1.40) : 12	468(1.30) : 6

Both males and females are adults of various ages.

^a As described in Watanabe et al. (1983).

^b Unit: g/day.

^c Individual values are shown.

^d —: No determination was made.

Seasonal variation in boiled rice intake was not significant ($p > 0.10$ by paired *t* test) when the winter and summer intake by the same subjects (109 males in 12 regions and 100 females in 11 regions) were compared.

Correlation between boiled rice intake and dietary cadmium intake

When the winter GM of boiled rice intake in each of 49 regions was compared with the counterpart value of dietary cadmium intake, the correlation was barely significant ($0.07 < p < 0.08$) for males with a correlation coefficient of 0.279 (data available in 29 regions), significant for females ($r = 0.493$, $p < 0.01$, $N = 40$) and also significant when the data for the two sexes were combined ($r = 0.370$, $p < 0.01$, $N = 69$). It should be added, however, that the boiled rice intake in a certain region with high cadmium intake was not always higher than the values in other regions (Fig. 1), as the small correlation coefficients indicate. The correlation of winter measures on individual basis was statistically significant although the correlation coefficient was rather small, i.e., $r = 0.138$ ($p < 0.01$; $N = 368$) for males, $r = 0.259$ ($p < 0.01$; $N = 674$) for females, and $r = 0.230$ ($p < 0.01$; $N = 1042$) for the combination.

Effects of urbanization on intakes of boiled rice

Analysis of boiled rice intake by age (Table 2) revealed that the daily intake varies depending on the decade of ages, and that the amount stays rather constant

Fig. 1. Correlation between boiled rice intake and dietary intake of cadmium by regions.

Each spot indicate GM of boiled rice intake and dietary intake of cadmium for a given region where 3 or more samples for either sex were available. Open circles are for males and solid ones for females.

The solid line

$$Y = 12.0 + 0.0466X \quad (\gamma = 0.279, 0.07 < p < 0.08, N = 29)$$

and the broken line

$$Y = -9.3 + 0.0836X \quad (\gamma = 0.493, p < 0.01, N = 40)$$

are the calculated regression lines for males and for females, respectively, where X is boiled rice intake (GM; g/day) and Y is dietary cadmium intake (GM; $\mu\text{g/day}$) by region.

TABLE 2. Daily boiled rice intake by age and sex

Age ranges	Males	Females
	GM ^a (GSD): N	GM ^b (GSD): N
20-29	911(1.42): 26	596(1.57): 36
30-39	909(1.42): 65	632(1.99): 138
40-49	902(1.49): 112	632(1.44): 253
50-59	863(1.43): 128	567(1.56): 205
60 and over	631(1.41): 37	545(1.48): 40

^a Unit: g/day.

at 30-49 years of age with decreasing tendency at advanced ages. Accordingly, female subjects at the ages of 30-49 years were selected from the examinees in the outskirts of the city of Sendai (the urban group of 17 females) and those in other parts of surrounding Miyagi Prefecture (the rural group of 132 females). Daily boiled rice intake in terms of GM (GSD): N was 321 g/day (1.34): 17 for the former group and 626 g/day (1.64): 32 for the latter, the difference being statistically significant ($p < 0.01$). Analysis of additional boiled rice samples (34 in total) collected from various parts of Miyagi Prefecture revealed that the cadmium content was 24.5 ng/g boiled rice (1.50): 34 as GM (GSD): N . Based on the boiled

rice intake and the average cadmium content in boiled rice, the rate of cadmium in boiled rice over cadmium in whole day diet (cited from Watanabe et al. 1984) was calculated on individual basis as

$$\frac{\text{boiled rice intake (g)} \times 0.0245 (\mu\text{g/g})}{\text{total dietary cadmium } (\mu\text{g})} \times 100 (\%)$$

When a normal distribution of the rate was assumed, the rate was $39.8 \pm 15.0\%$ (arithmetic mean $\pm$ arithmetic s.d.) for the urban group and $51.5 \pm 26.2\%$ for the rural group, the difference being statistically significant ($p < 0.05$).

Cadmium contents in alcoholic beverages

Through this survey were collected 80 samples of *sake* (rice wine) which were to be consumed at home by the examinees. The analysis for cadmium disclosed $3.17 \mu\text{g/liter}$ (1.52) : 80 for GM (GSD) : N. The corresponding values for store-bought samples were $2.20 \mu\text{g/liter}$ (1.59) : 40 and $2.12 \mu\text{g/liter}$ (1.59) : 29 for first grade and second grade *sake*, respectively. Analogous studies with several brands of Japanese beer revealed that the cadmium levels were well below $1 \mu\text{g/liter}$.

DISCUSSION

Concerning the food item that is the major source of the cadmium intake via diet, Mahaffey et al. (1975) reported that cadmium contents in grain and cereals will account for 22.8% (11.7 $\mu\text{g/day}$) of total daily cadmium intake (52.1 $\mu\text{g/day}$; the estimate by the 'market baskets' method for a standard 15-20 year-old American male). This percentage for grain and cereals was the largest among the 12 food categories studied. For Japanese diet in particular, Nogawa et al. (1978), Nogawa and Ishizaki (1979) and Shigematsu et al. (1979) reported a significant correlation between cadmium contents in rice consumed and intensity of environmental (nonoccupational) exposure to cadmium, suggesting that rice is a leading source of cadmium in Japanese diet. In fact, Tsuchiya and Iwao (1978) attributed 27 to 74% of total dietary intake of cadmium to grain and cereals (predominantly rice) in their study in cadmium-polluted and matched control areas in Japan. The positive relations observed in the present study between intake of rice and that of cadmium in diet are in accordance with these reports.

It was also possible to conduct trials for quantitative evaluation. Although no determination of cadmium contents in boiled rice was made on regional basis in the present study, the data are available for cadmium levels in boiled rice samples collected in Miyagi Prefecture, i.e., 24.5 ng/g as the mean and 10.9 and 55.1 ng/g as the 95% lower and upper confidence limits, respectively. Even though the possibility remains that cadmium levels in rice may be variable depending on the regions, the three concentrations were tentatively applied to the cases of minimum and maximum boiled rice intake in each sex (i.e., 557 g/day in Kagoshima and 1,247 g/day in Toyama for males, and 323 g/day in Tokyo and 804 g/day in Shimané for females; Table 1) to estimate the cadmium intake via

rice. The comparison with corresponding cadmium contents in 24-hour duplicates of diet (values cited from Watanabe et al. 1984) shows that the average share of cadmium intake via rice (estimated as described above) in total dietary cadmium intake is 34.0% (22.7 to 59.3% as the range for four cases) when the mean cadmium level in rice is applied. It is 14.5% (7.3 to 26.5%) with the 95% lower limit of confidence, and 76.6% (51.0 to 133.5%) with the 95% upper limit. Such role of rice as the dietary cadmium source may vary depending on the extent of urbanization as urban people eat less rice than rural people. It is quite probable, however, that very high cadmium intake, e.g., over 140 $\mu\text{g}/\text{day}$, may not be attributable solely to rice in non-polluted areas, as the rice with cadmium content of over 0.4 $\mu\text{g}/\text{g}$ (on unpolished rice basis; the concentration would correspond to ca. 150 ng cadmium/g boiled rice) is administratively excluded from dietary use (Ministry of Health and Welfare 1959).

In contrast, cadmium contents in *sake* (rice wine) were low in the range of 2–3 $\mu\text{g}/\text{liter}$ (Ishizaki et al. 1970; also present observation), and those in beer were even lower (present observation). Thus, these two alcoholic beverages, popular in rural males (75%) yet much less so among rural females (12%) (Chiba et al. 1983), will not be major sources of cadmium intake through daily food.

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