The daily fluorine and arsenic intake for residents with different dietaries and fluorosis risk in coal-burning fluorosis area, Yunnan, Southwest China

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Abstract The daily fluorine (F)/arsenic (As) intake (DFI/DAsI) for residents at different ages with different dietaries and dietary changes was investigated to analyze the fluorosis risk in coal-burning fluorosis area in Yunnan, Southwest China. The DFI for residents with a dietary of roasted corn and roasted chili was 5.06, 9.60, and 14.38 mg for age groups 3–7, 8–15, and over 15 years, respectively. Over 90 % of DFI was from roasted foodstuffs. The DFI for residents of the same age group living on rice and roasted chili was 1.94, 3.50, and 4.95 mg, respectively, which were less than that for the former dietary type, and 65 % of DFI was from roasted chili. The main sources for their DFI are roasted foodstuffs. Both were higher than the dietaries with non-roasted foodstuffs and the recommended daily allowances (RDAs) for USA and China at different levels. The DAsI for all residents ranged from 25 to 135 µg, and at this level of DAsI, it would not influence

human health. However, As pollution of roasted foodstuffs might have an important influence for the fluorosis. Residents are changing their staple food from roasted corn to rice, and especially, younger people are more focused on quality life. However, even if residents change their staple food, the habit of eating chili will not change, which also may cause them getting fluorosis. Developing economy, changing dietary types, and changing the habit of drying and keeping chili will help to reduce the fluorosis risk in coal-burning fluorosis area of Southwest China.

Keywords Daily fluorine intake · Daily arsenic intake · Roasted foodstuffs · Dietary types · Dietary development · Fluorosis risk

Abbreviations

F	Fluorine
As	Arsenic
DC	Dental caries
DF	Dental fluorosis
SF	Skeletal fluorosis
AI	Adequate intake
RDAs	Recommended daily allowances
DFI	Daily fluorine intake
DAsI	Daily arsenic intake
IOD	Improved oven for defluorination
PLFs	Permitted levels of fluorine
PLAs	Permitted levels of arsenic

Introduction

Fluorine (F) is an essential trace element for humans, because it plays an important role in the mineralization of bones and

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formation of dental enamel (Bell and Ludwig 1970). The deficiency of F may result in dental caries (DC) for children. However, excessive intake of F may have cumulative toxic symptoms such as dental fluorosis (DF) and skeletal fluorosis (SF) (Liteplo et al. 2002; Kaseva 2006) and other adverse health effects such as bone cancer, Down's syndrome, and renal failure (Harrison 2005).

Researchers have paid much attention to the dose-response relationships and tried to determine the safe doses (Cao et al. 1996; Jian and Chen 2006; Ponikvar et al. 2007; Xiang et al. 2009). The adequate intake (AI) for F from all sources is set at 0.05 mg/day/kg of body weight, which is recommended for all ages greater than 6 months; it is because it confers a high level of protection against DC and is associated with unknown and unwanted health effects (FNB 1997). In the USA, the recommended daily allowances (RDAs) are 1.5–2.5 mg/day for children aged 4–7 years and 1.5–4 mg/d for adults, respectively (BCLSNR 1980, 1989). The WHO guideline for daily intake is 2 mg/day for children and 4 mg/day for adults, respectively (WHO 1985, 2002). Accordingly, AI of 3.1–3.8 mg/day of F for adults is set and accepted by the German and Austrian Nutrition Society and the Swiss Nutrition Association (Reference Values for Nutrition Intake 2002). In China, the RDAs are different for different types of fluorosis area: The RDA for children aged 8–15 years is 2.0 mg/day, and for adults over 15 years, it is 3.0 mg/day in coal-burning fluorosis area, while the RDA for children aged 8–15 years is 2.4 mg/day, and for adults over 15 years, it is 3.5 mg/day in drinking water fluorosis area (WS/T87-1996).

There are mainly three types of endemic fluorosis: high-F drinking water (Abida et al. 2007; Mandinic et al. 2010), high-F brick tea (Cao et al. 1996, 2003), and coal-burning fluorosis (Ando et al. 2001; Finkelman et al. 1999; Dai et al. 2004, 2007, 2012). Zhaotong, in Yunnan, is a serious coal-burning endemic fluorosis area (Ye et al. 2004a, b; Luo et al. 2007, 2008, 2010, 2011; Li et al. 2012). There were 2,000,000 DF patients and 600,000 SF patients (Ye et al. 2004a), and the occurrence rate of DF patients still exceeded 50 % (Ye et al. 2004a, b). Furthermore, most elder fluorosis patients are also suspected with As poisoning, which is characterized by pigment precipitation (Luo et al. 2008). The serious influence of F on human health might be related with the combined effects of As-polluted roasted foodstuffs (An et al. 1992; Li et al. 1996; Luo et al. 2008; Dai et al. 2012).

In our previous study, we find that severe fluorosis areas and non-fluorosis areas exist in the same region and there are non-infected people in severe fluorosis areas and infected people in non-fluorosis areas in Southwest China as well (Luo et al. 2011). The prevalence rate of DF for children with different dietary types differs evidently: The prevalence rate of DF for children living on roasted corn before the age of 6 years is 100 % with nearly 95 % having mild to severe DF, while the prevalence rate of DF for children living on non-roasted corn

or rice is very low and all with very mild DF (Luo et al. 2011). However, several problems still need further studies. What are the differences in daily F/As intake (DFI/DAsI) for residents at different age groups and having different dietary types? What percentages of DFI/DAsI from different sources, including kinds of foodstuffs, drinking water, and air, are in total DFI/DAsI having different dietary types? Furthermore, what are the local residents' present dietary habits and how does it change in the future? From the current level of economic situation and the dietary habits of local residents, will the fluorosis phenomenon disappear naturally in the future?

To prevent fluorosis from happening, the F and As concentrations in the commonly consumed foodstuffs and drinking water and their consumption amount of residents at different ages were investigated to estimate the daily F and As intake, and the development process of their dietary types was carried out in "coal-burning" fluorosis in Zhaotong, Yunnan, Southwest China.

Material and methods

Study area

Zhaotong is at the junction of Sichuan, Yunnan, and Guizhou, and has a subtropical and warm plateau monsoon climate. Its topography varies and is complicated with plateaus, hills, basins, and valleys. The climate varies with the altitude: It is cool and rainy with an average annual temperature of 11–18 °C and an average annual precipitation of 900–1,200 mm at high altitudes, and it is comparatively dry and warm with an average annual temperature of 15–20 °C and an average annual precipitation of 660–1,000 mm at low altitudes (Luo et al. 2011). Furthermore, the rainy season occurs from June to October, just during the harvest season. Residents have to roast freshly harvested corn and chili by burning coal over open oven to dehydrate quickly and hang roasted chilies over the improved oven for defluorination (IOD) to keep dry chilies readily available whenever needed in high-elevation mountainous areas (called roasted corn and roasted chili). They just dry corn and chili by excess heat from cooking or by air naturally, but not with special open oven in the valley area (called non-roasted corn and non-roasted chili).

Two areas were selected as the study areas. Mangbu Town, in Zhenxiong County, is a mountainous region with an altitude of 1,600–1,900 m, and its prevalence rate of DF is 68.5 %, and residents live on roasted corn and roasted chili primarily, and on rice and roasted chili occasionally. Mugan Town, in Dagan County, is in a valley region with an altitude of 900–1,200 m, and its prevalence rate of DF is 10 %, and residents live on non-roasted corn and non-roasted chili primarily, and on rice and non-roasted chili occasionally (Luo et al. 2011).

Sample collecting and analysis

Foodstuffs and drinking water samples were collected from Mangbu Town and Mugan Town. The sampling sites included three villages—Yujiawan Village and Wantou Village in the township of Mangbu (typical severe fluorosis village, nearly all residents get severe DF), and Haizi Village in the township of Mugan (typical non-fluorosis village, the prevalence rate of DF is very low) (Fig. 1).

Three drinking water samples from these villages were collected from the groundwater sources. All groundwater samples came from fissure water. The fissure water is one of the main drinking water sources for villages and small towns (Luo et al. 2012). Before sampling, the sampling containers were decontaminated with nitric acid for 24 h, rinsed with tap water first, and finally washed by distilled water. We flushed the containers with sampling water three times at the sampling spots. Water samples were stored in pre-cleaned plastic bottles at 4 °C before being analyzed. According to HJ/T 164–2004, the F and As concentrations in groundwater samples need to be measured within 14 days.

The staple food including rice ($n=13$, n is the number of samples), corn flour ($n=25$), and noodle ($n=13$) was collected from local residents' home. In this study, we also collected local common vegetables including Chinese cabbage ($n=13$), potato ($n=13$), pickle ($n=13$), and chili ($n=25$). Corn flour was made after corn peel. Chili powder was directly crushed from chili hanging over IOD. According to eating habits of local residents, rice and vegetables were cleaned with distilled water before dried, but corn flour, noodle, and chili powder were dried without cleaning. All samples were

dried at 60 °C in baking oven and then sieved to 100 meshes for analysis.

Fluoride ion selective electrode and atomic fluorescence spectrometry methods were used to measure the F and As in drinking water, respectively. Fluorine in foodstuffs was determined by the combustion hydrolysis/fluoride ion selective electrode method: 1.0-g sample was put in a small ceramic boat covered with suitable quartz sand. The boat was gradually put into electric furnace at 1,000 °C, and meanwhile, the condensate was absorbed by 0.2 mol/L sodium hydroxide solution. Then, 5 mL total ionic strength adjusting buffer (TISAB) was added to tested solutions before determination by a fluoride selection electrode and a calomel reference electrode (Shanghai Precision and Scientific Instrument Co. Ltd., China). TISAB was prepared as follows: 145 g sodium chloride and 7.35 g sodium citrate were dissolved in 143 mL acetic acid, and the pH of solution was adjusted to 5.0–5.5 using 40 % sodium hydroxide solution (GB/T 4633-1997, Feng et al. 2004; Li et al. 2012). Arsenic in samples was measured by hydride generation/atomic fluorescence spectrometry method: Samples were digested with the mixed acid of nitric acid and perchloric acid using electric hot plate (GB/T 5009.11–2003), added with 1 mL HCl (36.5 %) and 1 mL reducing agent (2.5 % sulfoarea and 2.5 % ascorbic acid) fixed to 20 mL by ultrapure water, and measured by AFS-820 (Titan Instruments Company, Beijing, China) finally.

For quality control, standard reference materials (GBW10010 [rice, China], GBW10012 [corn, China], and GBW07602 [bush leaves, China] for corns) and blanks were randomly analyzed with each batch of samples. The correlation coefficients of both F and As standard curves reach 0.999. In all our F and As analyses, the relative standard deviation was less than 10 %.

Investigation method

The foodstuffs and drinking water consumptions of a total of 54 residents at different ages were investigated. We investigated 31 residents including 17 residents with a dietary of roasted corn and roasted chili and 14 residents with a dietary of rice and roasted chili in Mangbu Town, and 23 residents including 13 residents with a dietary of non-roasted corn and non-roasted chili and 10 residents with a dietary of rice and non-roasted chili in Mugan Town. The diets including all foodstuffs and drinking water were surveyed in 3 days by asking the housewives, weighed by our investigators (WS/T87-1996).

In addition, to find out the development process of local residents' dietary types, we surveyed 38 households for their present and future possible dietary types in Mangbu Town (as illustrated in Tables 4 and 5).

Fig. 1 Location map of the study areas

Calculation of DFI and DAsI

The main source of F and As of human intake is drinking water, indoor air, and foodstuffs (Cao et al. 1996; WS/T87-1996; Jian and Chen 2006; Ponikvar et al. 2007; Xiang et al. 2009):

$$\text{DFI/DAsI} = \sum C_i I_i \quad (1)$$

where DFI is the daily fluorine intake, DAsI is the daily arsenic intake, C_i is the F/As concentration in environmental medium (foodstuffs, drinking water, and indoor air), and I_i is the amount of daily intake of foodstuffs, drinking water, and indoor air.

Statistical analyses

The data were analyzed by using Microsoft Excel 2007 and SPSS 13.0.

Results

F and As concentrations

F and As concentrations in foodstuffs

From Table 1, F concentration in roasted corn in Mangbu Town (18.49 ± 8.23 mg/kg) is much higher than that in non-roasted corn in Mugan Town (3.17 ± 0.37 mg/kg) ($p < 0.01$). F in roasted corn is much higher than the permitted levels of F (PLFs) in grain (1.5 mg/kg) (GB/T 2762–2005) and fresh corn (below 1.5 mg/kg) (Li et al. 2012), and F in non-roasted corn was slightly higher than the PLFs in roasted corn and fresh corn. It showed that a large amount of F in roasted corn was caused by coal burning, but F in non-roasted corn increased less, which was consistent with several previous studies (Dai et al. 2004, 2007; Luo et al. 2007, 2010, 2011). F in rice (0.97 ± 0.56 and 1.09 ± 0.24 mg/kg, respectively) and noodle (2.02 ± 0.90 and 1.93 ± 0.87 mg/kg, respectively) in both areas was much less than that of the roasted corn ($p < 0.01$). F in rice and noodle in Mangbu and Mugan Town was similar to the PLFs in rice and other grains (1.0 and 1.5 mg/kg, respectively) (GB/T 2762–2005). Fluorine in roasted chili powder in Mangbu Town (92.35 ± 17.55 mg/kg) was much higher than that in both the other vegetables in this study and the PLFs in vegetables (2.0 mg/kg) (GB/T 2762–2005). Fluorine in roasted chili powder in Mangbu Town was 5–30 times that in non-roasted chili in Mugan Town (3.51 ± 0.51 mg/kg). F in Chinese cabbage, potato, and pickle was similar to the PLFs in vegetables.

As shown in Table 1, As concentration in roasted corn in Mangbu Town (0.162 ± 0.121 mg/kg) was much higher than the that in non-roasted corn in Mugan Town (0.051 ± 0.020 mg/kg) ($p < 0.01$). It is consistent with the previous research results that roasted corn and chili are seriously contaminated with As by dozens of times (Luo et al. 2008, 2010; Li et al. 2012). Arsenic concentrations in most staple food including non-roasted corn (0.051 ± 0.020 mg/kg), rice (0.110 ± 0.032 and 0.075 ± 0.032 mg/kg), and noodle (0.024 ± 0.005 and 0.031 ± 0.008 mg/kg) in both areas were much lower than the permitted levels of As (PLAs) in rice and other grain (0.15 and 0.2 mg/kg, respectively) (GB/T 2762–2005). Arsenic in roasted chili (0.782 ± 0.211 mg/kg) and non-roasted chili (0.230 ± 0.082 mg/kg) was much higher than the PLAs in vegetables (0.05 mg/kg). Arsenic in pickle was much less than the PLAs in vegetables. Arsenic in Chinese cabbage and potato was slightly more than the PLAs in vegetables.

In conclusion, except that F and As in roasted corn and roasted chili in Mangbu Town were much higher than those in non-roasted corn and non-roasted chili in Mugan Town, F and As in other foodstuffs in these two places were similar. It is worth noting that the corn flour was made after corn peel. F and As concentrations in peeled corn are reduced at different levels, especially As can be reduced by 70 %, compared with those in unpeeled corn (Li and Luo 2010). The residents eat a little chili powder for seasoning purpose, not as a true vegetable.

F and As concentrations in drinking water

There were two drinking water sources in Mangbu Town and one source in Mugan Town. As showed in Table 1, F and As concentrations in drinking water from these water sources were 0.21 mg/L (mean) and 0.22 mg/L, and $0.187 \mu\text{g/L}$ (mean) and $0.310 \mu\text{g/L}$, respectively. The results were consistent with previous studies (Luo et al. 2007, 2008, 2012; Dai et al. 2004). All were much lower than the PLFs and PLAs in drinking water (1.0 and 0.01 mg/L, respectively) (GB 5749–2006) and the recommendations (1.5 mg/kg and 0.01 mg/L, respectively) by WHO (1996), and also much lower than the fluorosis area Shannxi (1.17 mg/L and $10 \mu\text{g/L}$, respectively) (Zhu et al. 2006)).

F and As concentrations for indoor air in bedroom and living room

Almost all households were IOD users and the air quality has met Chinese standards in Zhaotong City (Liu et al. 1999; Li and Long 2005). F and As concentrations for indoor air in the baking room were much higher than those in the bedroom and living room (Jin et al. 2003; Liu et al. 2013). According to our field investigation, the baking room and living room are

Table 1 F and As concentrations in foodstuffs from households and drinking water from water source in investigated areas (dry basis, mg/kg)

Area		Rice		Corn		Noodle		Chili		Chinese cabbage		Potato		Pickle		Drinking water	
		F	As	F	As	F	As	F	As	F	As	F	As	F	As	F (mg/L)	As (μg/L)
Mangbu Town	<i>n</i>	8		15 ^a		8		15 ^a		8		8		8		2	
	min	0.39	0.032	7.10	0.021	0.81	0.005	101.02	0.548	1.07	0.023	0.98	0.007	0.23	0.035	0.15	0.127
	max	1.63	0.153	28.62	0.262	2.89	0.028	219.44	1.024	4.31	0.122	3.57	0.025	0.89	0.164	0.26	0.247
		0.97	0.110	18.49	0.162	2.02	0.024	154.25	0.782	3.09	0.072	2.21	0.016	0.55	0.114	0.205	0.187
	<i>s</i>	0.56	0.032	8.23	0.121	0.81	0.005	57.55	0.211	1.07	0.045	1.19	0.008	0.27	0.058		
Mugan Town	<i>n</i>	5		10 ^b		5		10 ^b		5		5		5		1	
	min	0.24	0.032	2.37	0.022	0.87	0.008	2.98	0.134	0.63	0.038	0.74	0.000	0.34	0.010	0.22	0.310
	max	1.30	0.100	3.91	0.089	2.68	0.037	3.99	0.308	3.21	0.217	3.51	0.012	1.44	0.108		
		1.09	0.075	3.17	0.051	1.93	0.031	3.51	0.230	2.27	0.128	2.18	0.006	1.04	0.067		
	<i>s</i>	0.24	0.032	0.67	0.020	0.87	0.008	0.51	0.082	1.34	0.076	1.23	0.005	0.54	0.049		

^a Roasted

^b Non-roasted

separate and independent from one another. Moreover, the baking room is generally enclosed during baking time of 10–15 days, and F and As concentrations in baking room have a little influence on human health. Therefore, according to references and our field investigation, we did not measure the F and As concentrations for indoor air quality. From the data of Zhenxiong County Environment Survey Station, the average F concentration for indoor air in bedroom and living room was 0.007 mg/m³, and As concentration for indoor air was considered as 1.6 μg/m³ according to Jin et al. (2003).

Food consumption of residents

Due to lack of reliable transportation and poor economy in the studied area, most people cannot afford commodity grain such as rice or wheat flour. The diet structure of countrymen is very simple. Most of them have to feed with their own grains and vegetables. They seldom eat meat except on important occasions. In addition, all local residents including weaning infants love chili as their daily necessary seasoning. Both adults and children like to drink unboiled water. They are not in a habit of drinking tea or beverage. They seldom brush teeth.

Based on our investigation, Table 2 shows daily foodstuff and drinking water consumption in two investigated areas. We could see that the diet structure of both areas is similar except for staple food and chili type. It is because the two areas are in the same geographical region. According to WS/T87–1996, an adult aged over 15 years needs 12 m³ of air per day, and a child aged 8–15 years needs 9 m³ of air per day. According to oxygen demand of different ages, we assume that a child aged 3–7 years needs 6 m³ of air per day.

DFI and DAsI of residents

Based on F and As concentrations in the selected foodstuff materials and daily food consumption of residents in the [F and As concentrations](#) and [Food consumption of residents](#) sections, we calculated DFI and DAsI of residents with these dietary types using Eq. (1).

DFI of residents

From Table 3, the DFI for residents with the dietary type of roasted corn and roasted chili for age groups 3–7, 8–15, and over 15 years was 5.06, 9.60, and 14.38 mg, respectively, all of which were much higher than that for the residents in the same age group with other dietary types. The DFI for residents of the same age groups with the dietary type of rice and roasted chili (1.94, 3.50, and 4.95 mg, respectively) was higher than that of the non-roasted corn and non-roasted chili type (1.19, 2.05, and 2.97 mg, respectively) and the rice and non-roasted chili type (0.85, 1.40, and 1.91 mg, respectively).

From Fig. 2 (DFI), for residents with the dietary type of roasted corn and roasted chili, DFI from roasted corn accounted for 70 % of total DFI, and from chili, it accounted for 23 %. For residents with the dietary type of rice and roasted chili, DFI from chili accounted for 65 % of total DFI. Therefore, roasted corn and roasted chili are the main sources of DFI for these residents. However, for residents with the dietary types of both non-roasted corn/non-roasted chili and rice/non-roasted chili, DFI from chili can be ignored. The main sources of DFI for the two types are staple food and drinking water.

Table 2 Daily food consumption in investigated areas

Area	Age (years)	Rice ^a (kg)	Corn ^a (kg)	Noodle (kg)	Chili (kg)	Chinese cabbage (wet basis, kg)	Potato (wet basis, kg)	Pickle (wet basis, kg)	Drinking water (L)
Mangbu Town	3–7	0.21±0.07	0.18±0.03	0.05±0.03	0.008±0.003	0.08±0.04	0.20±0.11	0.04±0.02	1.1±0.2
	8–15	0.38±0.10	0.35±0.05	0.11±0.07	0.012±0.005	0.11±0.05	0.26±0.13	0.06±0.02	1.8±0.4
	Over 15	0.57±0.12	0.54±0.11	0.16±0.08	0.016±0.005	0.15±0.09	0.30±0.13	0.11±0.05	2.7±0.7
Mugan Town	3–7	0.24±0.03	0.19±0.04	0.06±0.02	0.007±0.002	0.06±0.04	0.22±0.10	0.05±0.02	1.2±0.3
	8–15	0.40±0.08	0.34±0.06	0.12±0.05	0.014±0.004	0.10±0.07	0.29±0.12	0.08±0.03	2.0±0.5
	Over 15	0.51±0.11	0.51±0.09	0.18±0.09	0.018±0.006	0.14±0.10	0.34±0.14	0.12±0.05	2.9±0.7

^a Rice and corn are two different types of staple foods for different residents**Table 3** Daily fluorine intake (DFI) and daily arsenic intake (DAsI) of residents at different ages with different dietary types

Area	Dietary types	Age (years)	DFI (mg)		DAsI (μg)											
			Com/ rice	Noodle	Subsidiary food	Chili powder	Drinking water	Air	Total	Rice/ corn	Noodle	Subsidiary food	Chili powder	Drinking water	Total	
Mangbu Town	Roasted corn + roasted chili	3-7	3.33	0.10	0.13	1.23	0.23	0.04	5.06	29.16	1.00	3.50	6.24	0.21	9.60	49.71
		8-15	6.47	0.22	0.16	2.31	0.37	0.06	9.60	56.70	2.20	5.47	11.70	0.34	14.40	90.80
		over 15	9.98	0.32	0.20	3.24	0.55	0.08	14.38	87.48	3.20	7.04	16.38	0.50	19.20	133.80
Mugan Town	Rice + roasted chili	3-7	0.20	0.10	0.13	1.23	0.23	0.04	1.94	23.10	1.00	3.50	3.04	0.21	9.60	40.45
		8-15	0.37	0.22	0.16	2.31	0.37	0.06	3.50	41.80	2.20	5.47	4.56	0.34	14.40	68.76
		Over 15	0.55	0.32	0.20	3.24	0.55	0.08	4.95	62.70	3.20	7.04	6.08	0.84	19.20	99.06
	Non-roasted Corn + non-roasted chili	3-7	0.60	0.12	0.14	0.02	0.26	0.04	1.19	9.69	1.86	1.96	1.61	0.37	9.60	25.09
		8-15	1.08	0.23	0.18	0.06	0.44	0.06	2.05	17.34	3.72	3.48	3.68	0.62	14.40	43.24
		over 15	1.62	0.35	0.22	0.07	0.64	0.08	2.97	26.01	5.58	4.59	4.37	0.90	19.20	60.65
	Rice + non-roasted chili	3-7	0.26	0.12	0.14	0.02	0.26	0.04	0.85	18.00	1.86	1.96	1.81	0.39	9.60	33.62
		8-15	0.44	0.23	0.18	0.06	0.44	0.06	1.40	30.00	3.72	3.48	3.05	0.60	14.40	55.25
		Over 15	0.56	0.35	0.22	0.07	0.64	0.08	1.91	38.25	5.58	4.59	4.34	0.87	19.20	72.83

DAsI of residents

From Table 3, the average DAsI for residents with the dietary type of roasted corn and roasted chili in age groups 3–7, 8–15, and over 15 years was 49.71, 90.80, and 133.80 μg , respectively, which were slightly higher than that for residents in the same age group with rice and roasted chili (40.45, 68.76, and 99.06 μg , respectively), non-roasted corn and non-roasted chili (25.09, 43.24, and 60.65 μg , respectively), and rice and non-roasted chili (33.62, 55.25, and 72.83 μg , respectively). The DAsI for residents with dietary types of rice/non-roasted chili and non-roasted corn/non-roasted chili was similar.

As shown in Fig. 2 (DAsI), DAsI from staple food accounts for over 45 % of total DAsI, and from air, it accounts for more than 15 % for all residents consuming any kind of diet; DAsI from drinking water has very little influence and can be ignored.

Development process of the dietary types

From Table 4, the households whose staple food were rice or mainly rice accounted for 52.6 % of all investigated households, and the other 47.4 % lived on corn or mainly corn. Specifically, the staple food of all the householders below 35 years old was rice or mainly rice, while the staple food of about 65 % of the other householders over 35 years old was corn or mainly corn. From Table 5, the reason for 66.7 % of householders choosing corn as staple food was for economic reason since rice is more expensive than their own grown corn, and the reason for 33.3 % of householders choosing corn was because corn is more delicious. The reason for 90.0 % of householders choosing rice as staple food was because rice is more delicious and easier to cook. Over 60 % of householders would like to eat rice or mainly rice as staple food, while only 18.4 % of householders with 100 %

householders aged over 35 would like to eat corn or mainly corn as staple food. This means that rice is their preferred staple food for local residents. Almost all residents would not change their habit of eating chili as seasoning.

Discussion

As dental calcification of children is completed before an age of 6–8 years old, DFI for children during this period will decide whether their teeth will take pathologic change. The DFI for the children aged 3–7 years with a dietary of roasted corn and roasted chili was 5.06 mg, which was much higher than the RDAs of USA (1.5–2.5 mg) (BCLSNR 1980). The DFI of the children aged 3–7 years with dietaries of rice/roasted chili (1.94 mg) and non-roasted corn/non-roasted chili (1.19 mg) was within the RDAs of USA. The DFI of the children aged 3–7 years with a dietary of rice/non-roasted chili (0.85 mg) was less than the RDAs in USA. According to DF epidemiological investigation for residents, we concluded that the DF prevalence rates for children aged 9–14 years with different dietary types before the age of 6 years were 100 % with 95 % having very mild DF for children living on roasted corn and roasted chili, 5.6 % with 100 % having very mild DF for children living on rice and roasted chili, 16.7 % with 100 % having very mild DF for children living on non-roasted corn and non-roasted chili, and no one got DF living on rice and non-roasted chili (Luo et al. 2011). The results verified the adaptation of RDAs of USA in coal-burning fluorosis regions in Southwest China. The AI for fluorine from all sources is set at 0.05 mg/day/kg bodyweight (FNB 1997). It is assumed the weight of a child aged 3–7 years is 10–20 kg and the AI for F is calculated as 0.5–1 mg. Therefore, the children have little risk for getting DC in this

Fig. 2 Percentages of various sources in total DFI and DAsI

Table 4 The present and future possible dietary style of respondents

Variable	Age group (years)	20–35 (11)		35–45 (13)		>45 (14)		Total	
		Count	Percent	Count	Percent	Count	Percent	Count	Percent
Present staple food	Rice	8	72.7	2	15.4	1	7.1	11	28.9
	Rice based, corn occasionally	3	33.3	2	15.4	4	28.6	9	23.7
	Corn based, rice occasionally	0	0	8	61.5	8	57.2	16	42.1
	Corn	0	0	1	7.7	1	7.1	2	5.3
	Total	11	100	13	100	14	100	38	100
Future staple food	Rice	9	81.8	3	23.2	2	14.3	14	36.8
	Rice based, corn occasionally	2	18.2	5	38.4	10	71.4	17	36.8
	Corn based, rice occasionally	0	0	5	38.4	2	14.3	7	18.4
	Total	11	100	13	100	14	100	38	100
Chili powder	Change	1	100	0	0	0	0	1	2.6
	Not change	10	27.0	13	35.1	14	37.8	37	97.4

study area. It is consistent with Lu et al.'s (2009) investigation that the prevalence rate for dental caries for children in Zhaotong was the lowest in 16 regions of Yunnan Province. Furthermore, if residents have continuously exposed F-contaminated environment through ingestion and inhalation, they will get SF at their 40s. There have been several reports that SF was very popular in middle ages and elders (Jian and Chen 2006; Luo et al. 2008). The DFI for the children (7–15 years) and adults (over 15 years) with a dietary of roasted corn and roasted chili was 9.60 and 14.38 mg, respectively, which were much higher than RDAs of USA (1.5–4.0 mg) (BCLSNR 1989) and of China (2.0 and 3.0 mg, respectively) (WS/T 96–2005). The DFI for the children and adults with a dietary of rice and roasted chili was 3.50 and 4.95 mg, respectively, both of which were slightly higher than the RDAs of USA and China. The DFI for the children and adults with dietaries of both non-roasted corn/non-roasted chili (2.05 and 2.97 mg, respectively) and rice/non-roasted chili (1.40 and 1.91 mg, respectively) was less than the RDAs of USA and China. According to Jian and Chen (2006), residents did not get SF when DFI was 1.81 mg, while the prevalence rate of SF of the elders over 55 years old reached 28.6 % when DFI was 4.48 mg. From this, the residents with a dietary of roasted corn

and roasted chili have a high risk for getting SF and the residents living on rice and roasted chili also have a certain risk for getting SF. However, we still lack information on the SF prevalence rate for residents with different dietary types, and further study is needed to find the corresponding relation between the DFI and SF prevalence rate with different dietary types in Southwest China.

DAI for residents with different dietary types at different ages ranged from 25 to 135 μg , all of which were lower than the recommendation (128 μg) by FAO/WHO (1988) and (Li et al.'s (2006) research value (276.1 μg). Therefore, As polluted in foodstuffs alone will not influence human health. There was not much difference in DAI between roasted corn and rice as staple food. However, compared with the DAI of residents living on fresh corn, the DAI for roasted corn increases greatly (Li et al. 2012). As and F may have synergy effect on fluorosis and As poisoning (An et al. 1992; Li et al. 1996). Therefore, the As-polluted roasted corn and chili by coal burning may have an important influence on fluorosis and As poisoning.

Local residents are changing their staple food from corn flour to rice, and especially, younger people who value quality life prefer to spend more on rice because it is more delicious and much easier to cook. However, even if local residents have changed their staple food, they will not change their habit of chili powder as seasoning for a long time. So we should pay more attention to F intake from chili which may have influence on human health. People have the habit of stringing chilies together and hanging them on the IOD to roast and keep them dry so they can take them whenever needed during wet seasons. F in coal is easily absorbed by chilies in the process of adding coal during cooking. F concentration in chilies can even reach 455 mg/kg (Luo et al. 2010). In our studies, if a person eats 20 g of chili per day, he/she

Table 5 Main reason for choosing present staple food

Choice	Reasons (multiple choice)	Count	Percent
Corn or mainly corn	More delicious	6	33.3
	Economic reasons	12	66.7
	Eating corn makes people feel strong to work	3	16.7
Rice or mainly rice	More delicious	18	90.0
	Easier to cook	8	40.0

will take F of 9.9 g per day, which is much higher than the RDAs of USA and China.

From the economic situation of Zhaotong City, how much is the risk of fluorosis? The annual income of rural residents has been increasing yearly in Zhaotong. The average annual income for farmers in 2012(\$638) was three times that in 2003 (Statistical Bureau of Zhaotong City 2003–2012). However, Zhaotong ranks last in 14 cities of Yunnan Province. According to our field investigation, the economy situation and dietary habits of residents in Mangbu Town are better than other remote towns. People in developed regions can hardly imagine what a rough life the local countrymen living in mountainous areas have. They have to live on roasted corn and chili as their staple food and mainly vegetable once they are weaned. Therefore, we must see the difficulty to change the dietary habits of residents and to reduce the fluorosis risk in rural areas.

In conclusion, some measures can be taken to reduce fluorosis risk: (1) vigorously develop the local economy and encourage and guide the residents to eat rice as staple food, not roasted corn flour. All levels of governments have to offer certain subsidies to residents in the future. And, (2) it is very hard to give up chili powder as seasoning for local residents. Local centers for disease control and prevention should guide the residents to keep chili in sealed bags after drying and to avoid hanging it over IOD all the time.

Conclusions

The DFI for residents with a dietary of roasted corn and roasted chili was 5.06, 9.60, and 14.38 mg for age groups 3–7, 8–15, and over 15 years, respectively. Over 90 % of DFI was from roasted foodstuffs. The DFI for residents of the same age group living on rice and roasted chili was 1.94, 3.50, and 4.95 mg, respectively, which are less than that in the former dietary type, and 65 % of DFI was from roasted chili. The main sources for their DFI are roasted foodstuffs. Both were higher than the dietaries with non-roasted foodstuffs and the recommended daily allowances (RDAs) for USA and China at different levels. The DASI for all residents ranged from 25 to 135 µg, and at this level of DASI, it would not influence human health. However, As pollution of roasted foodstuffs might have an important influence for the fluorosis. Residents are changing their staple food from roasted corn to rice, and especially, younger people are more focused on quality life. However, even if residents change their staple food, the habit of eating chili will not change, which may also cause them getting fluorosis. Developing economy, changing dietary types, and changing the habit of drying and keeping chili will

help to reduce the fluorosis risk in coal-burning fluorosis area of Southwest China.

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