African Journal of Food Science Vol. 5(10), pp. 555-567, 30 September, 2011
Available online http://www.academicjournals.org/AJFS
ISSN 1996-0794 ©2011 Academic Journals

Full Length Research Paper

Daily dietary intake of iodine by adolescents in three residential care orphanages in southern Ghana

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Accepted 2 August, 2011

The essential mineral iodine plays an important role in early growth, cellular metabolism and the proper development of the brain; data on the daily dietary intake of iodine by adolescents in residential care orphanages in Ghana are scarce. Consequently, the adequacy of their dietary intake of iodine cannot be assessed. The dietary intake of iodine by adolescents in three residential care orphanages (Osu, Tutu-Akwapim and Teshie) in Southern Ghana have been evaluated by sampling the 24 h duplicate diets of the adolescents for 7-consecutive days using the duplicate diet sampling technique. The iodine content was determined by radiochemical neutron activation analysis (RNAA). Mean daily iodine content in the blended lyophilized 24 h duplicate diets were 287 ± 95, 286 ± 109 and 961 ± 142 ng g^{-1} lyophilized matter for Osu, Tutu-Akwapim and Teshie orphanages, respectively. The average iodine intake by the adolescents were 102 ± 25, 115 ± 25 and 340 ± 117 µg day^{-1} for Osu, Tutu-Akwapim and Teshie orphanages, respectively. The intake of iodine by Osu and Tutu adolescents though lower than the recommended daily allowance (RDA) of 150 µg day^{-1}, are within the normal 100 to 150 µg day^{-1} iodine intake common in non-iodine deficient countries of the world.

Key words: Ghana, adolescents, dietary intake, duplicate diet, iodine, orphanage.

INTRODUCTION

The United Nations (UN) convention on the rights of the child (1990), Article 20, stipulates that "a child temporarily or permanently deprived of his or her family environment, or in whose own best interests cannot be allowed to remain in that environment, shall be entitled to special protection and assistance provided by the State. States Parties shall in accordance with their national laws ensure alternative care for such a child. Such care could include, inter alia, foster placement, kafalah of Islamic law, adoption or if necessary placement in suitable institutions for the care of children" (UNICEF, 2011). In Ghana, orphaned, neglected and abused children (including adolescents) are mostly kept and cared for in residential care orphanages till they become adults.

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The activities of these residential care orphanages are supervised and monitored by the Government of Ghana through the Department of Social Welfare (DSW) of Ghana's Ministry of Employment and Social Welfare (DSW, 2008). The ultimate aim of the Government of Ghana is to safeguard the interest and wellbeing of the children in these orphanages. The operations of the orphanages are expected to comply with the requirements of the Children's Act of Ghana (ACT 560 of 1998), the United Nations Convention of the Rights of the Child (UNCRC) of 1990, the United Nations draft guidelines for the pro-tection and alternative care of children without parental care, and, the Government of Ghana's regulations for care and protection of children without appropriate parental care (DSW, 2008). Adolescents constitute majority of the orphaned, neglected and abused children living in most residential care orphanages in Ghana.

Adolescence is one of the most dynamic periods of human development (WHO, 2006; Story, 1992). Adolescence is a time of rapid and intense growth, with adolescents gaining up to 45% of their skeletal growth and 15 to 25% of their adult height (Rees and Christine, 1989). During the growth spurt of adolescence, up to 37% of total bone mass may be accumulated (Key and Key, 1994). Nutrition influences growth and development throughout infancy, childhood and adolescence; it is however during the period of adolescence that nutrient needs are the greatest (Lifshitz et al., 1993). Yet, interest in the health of adolescents is relatively recent, with the exception of adolescent pregnancy. A focus on nutrition is even more recent (WHO, 2005). Adolescence provides an opportunity to prepare for a healthy and productive life and to prevent the onset of nutrition-related chronic diseases during adulthood (WHO, 2006; Story, 1992; Klimis-Zacas et al., 2007). Despite the importance of healthy eating during adolescence, many adolescents' diets in most developing countries do not meet the recommended dietary intake of most micronutrients including iodine (Adelekan, 2003). The overwhelming importance of nutritional iodine is because it is an indispensable component of the thyroid hormones, thyroxine (T4) and triiodothyronine (T3) (Goldhaber, 2003); comprising 65 and 59% of their respective weights (Institute of Medicine, 2001). The thyroid hormones play an important role in cellular metabolism, early growth and development of most organs especially the brain (Institute of Medicine, 2001). Adolescents need a constant supply of these hormones. To date, no data on the dietary intake of iodine have been published for the Ghanaian adolescent population living in residential care orphanages. This makes it difficult to assess whether their dietary supplies of iodine are adequate on the basis of the recommended daily allowance (RDA) of 150 µg day^{-1} (Institute of Medicine, 2001) and on the basis of the 100 to 150 µg day^{-1} normal iodine intake common in non-iodine deficient countries of the world (Hassanien et al., 2003).

Most commonly used analytical techniques for the measurement of iodine in food are colorimetry based on catalytic reactions, inductively coupled plasma mass spectrometry (ICP-MS), cathodic stripping voltametry (CSV) and gas chromatography (GC) (Flores et al., 2007). Other techniques are ion selective electrodes, atomic absorption spectrometry (AAS), neutron activation analysis (NAA), isotope dilution resonance ionization mass spectrometry (ID-IMS) and energy dispersive X-ray fluorescence spectrometry (EDXRF) (Bhagat et al., 2007; Nogueira et al., 1998; Haldimann et al., 2005; Varga, 2007). NAA is however less frequently used because of the necessity of accessing a nuclear reactor (Winger et al., 2008; Žukowska and Biziuk, 2008). NAA however, offers the advantage of simultaneous quantification of many elements in a small amount of sample and, high sensitivity and selectivity (Žukowska and Biziuk, 2008; Kučera et al., 2001). There are several approaches to the use of NAA for iodine determination. These are instrumental neutron activation analysis (INAA), epithermal neutron activation analysis-Compton suppression counting (ENAA-CSC), preconcentration neutron activation analysis (PCNAA) and radiochemical neutron activation analysis (RNAA). RNAA using γ-spectrometry of the ^{128}I-induced radionuclide provides a detection limit good enough for low level iodine determination in foods (Kučera et al., 2001).

Sample decomposition is a critical step in iodine determination in food. This is due to the high volatility of iodine. Therefore, during sample digestion, iodine is usually transformed into a non-volatile chemical form [iodide (I^-) or iodate (IO_3^-)] to avoid losses during the digestion (Knapp et al., 1998). Four digestion methods are generally used for the decomposition of food samples for iodine determination. The methods are: dry ashing (alkaline fusion), wet ashing, Schöniger combustion and alkaline leaching (Knapp et al., 1998). Schöniger combustion is a very sensitive sample decomposition technique and has been successfully applied to determine trace amounts of iodine in food samples (Fecher, 1998). The technique has several advantages inspite of the small amount of sample that can be digested. The technique is very simple and fast; it is accomplished using inexpensive glassware. There are fewer risk of contamination because commercial oxygen which is used as an aid for combustion is considered pure with respect to trace element content (Flores et al., 2007).

In this study, the dietary intake of iodine by adolescents (12 to 15 years) in three residential care orphanages (Osu, Tutu-Akwapim and Teshie), all located in Southern Ghana was evaluated by sampling their 24 h duplicate diet for 7-consecutive days. Iodine content was determined by radiochemical neutron activation analysis (RNAA). The RNAA method was based on 1 min neutron irradiation of the lyophilized diet samples to induce the short-lived ^{128}I radionuclide through the reaction ^{127}I (n, γ) ^{128}I. Mineralization of the samples was achieved by Schoniger combustion using pure oxygen and NH_4NO_3. Iodine was separated by solvent extraction using classical oxidation-reductive stripping-oxidation cycle with $NaNO_2$ and Na_2SO_3. The extractant was chloroform. The γ-radiation intensity of the separated ^{128}I in the chloroform-extract was measured by γ-spectrometry at the 442.9 keV γ-energy of ^{128}I.

The study endeavours to contribute reliable and accurate data on the dietary intake of iodine by the adolescent population living in three residential care orphanages (Osu, Tutu-Akwapim and Teshie), and to assess whether their dietary supply of iodine is adequate on the basis of the United States Institute of Medicine's recommended daily allowance (RDA) of 150 µg day^{-1}.

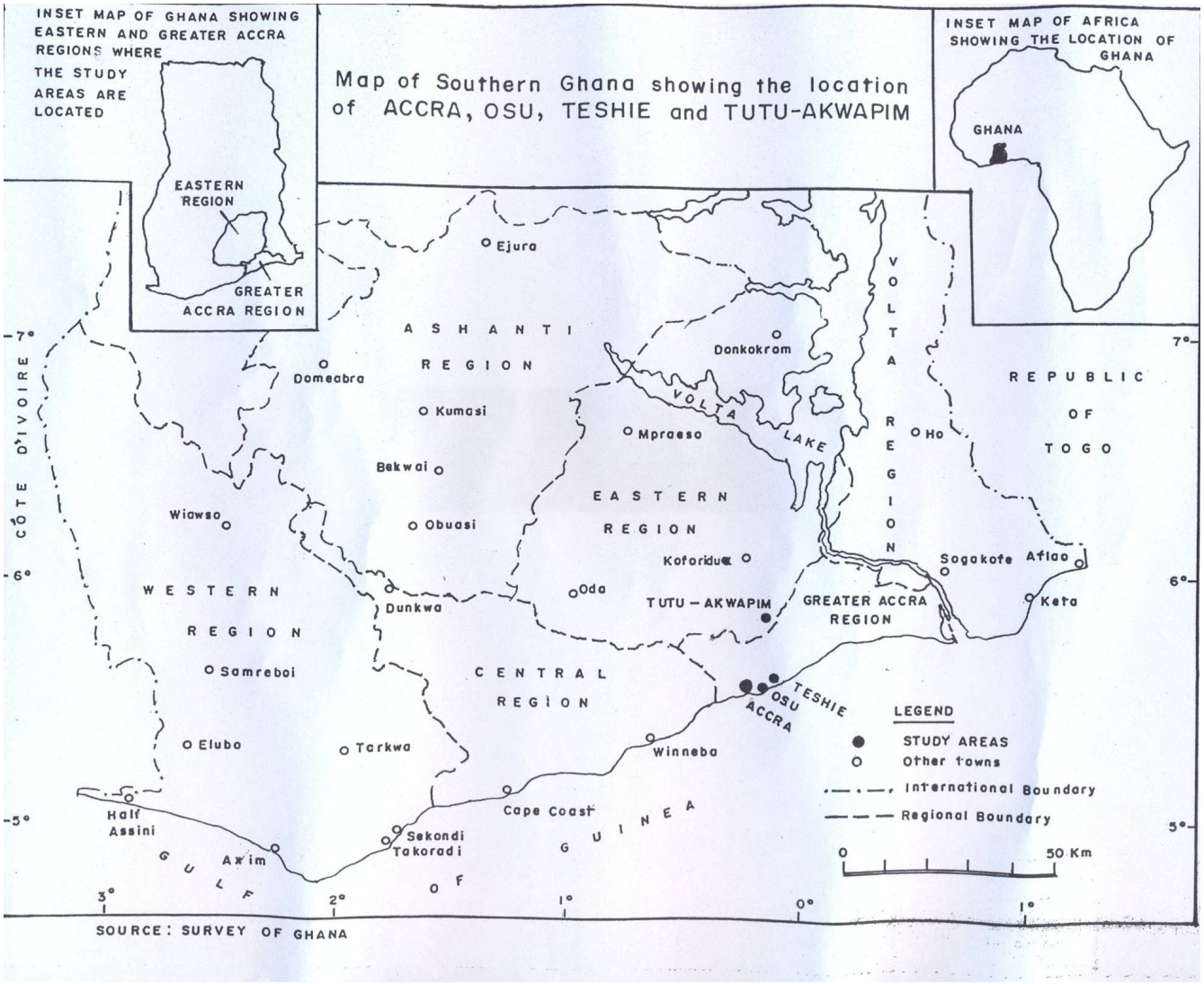

Figure 1. Map of Southern Ghana showing the sampling areas.

The study will also assess whether the dietary intake of iodine by the adolescents are within the normal 100 to 150 µg day^{-1} iodine intake common in non-iodine deficient countries of the world. The study will also provide nutritional information on the background iodine levels in the 24 h duplicate diet of the adolescents.

MATERIALS AND METHODS

Geographical location of orphanages

Ethical approval for the study and for the collection of the 24 h duplicate meals of the adolescents from the orphanages (Osu Children's Home, Tutu-Akwapim Trinity Foundation orphanage and Teshie orphanage) was given by the Department of Social Welfare of Ghana's Ministry of Employment and Social Welfare.

The Trinity Foundation Orphanage, is situated at Tutu-Akwapim. Tutu is a small town on the Akwapim Hills in the Eastern region of Ghana. The Akwapim Hills is located about 50 km northeast of Accra, the capital city of Ghana. The Hills ranges from 350 to 500 m above sea level, and covers an area of 450 km^2. Both Osu and Teshie Children's Homes are located in the Greater Accra region of Ghana. Osu Children's Home is situated at Labone and is about 5.5 km from Accra City Centre. Teshie is located 12 km from Accra City Centre. The study and sampling locations are presented in Figure 1.

Anthropometric measurements

The total number of orphans and the number of adolescents (aged 12 to 15 years) at the time of the study are presented in Table 1. Anthropometric measurements (body weight) were performed each morning before breakfast for the 7-consecutive sampling days, with

Table 1. Anthropometric measurements and number of adolescents

Orphanage	Age (years)		Body weight (kg)		Adolescents population*
	$\bar{x} \pm s$	Range	$\bar{x} \pm s$	Range	
Tutu-Akwapim	13.65 ±1.09	12 -15	47.83 ± 7.03	37.5 - 62	26 (42)
Osu	13.72 ±1.26	12 -15	49.82 ± 8.76	35 - 79	73 (256)
Teshie	14.27 ±0.96	13 - 15	46.82 ± 10.55	34.5 - 62.5	35 (48)

Number of adolescents, 12 to 15 years old (Total number of children in orphanage).

the adolescents wearing light clothing without shoes (Klimis-Zacas et al., 2007). The body weights of the studied participants were measured using a well calibrated portable weighing scale. The body weights were measured to the nearest 0.5 kg (Table 1).

Collection and processing of food duplicates

The study was carried out in August to September 2008 at Osu and Teshie orphanages and August to September 2009 at Tutu-Akwapim Trinity Foundation Orphanage. The study population in all three orphanages consisted of adolescents between the ages of 12 to 15 years. The entire study population in all three orphanages consumed a normal mixed diet, none was on a special diet and none was a vegetarian. All subjects had normal eating habits (Boocher et al., 2002; Seifert and Anke, 2000; Fromme et al., 2007). At each orphanage, the adolescents consume the same meal prepared from the same kitchen.

During the study period, three served meals (including water) for the study subjects were randomly and directly selected at each meal time over a 24 h period for 7-consecutive days including weekends (Smrkolj et al., 2005). The inclusion of weekends was necessary because eating habits change during weekends and therefore it was imperative to incorporate fluctuations in dietary patterns from weekdays to weekends (Seifert and Anke, 2000; Lightowler and Davies, 2002). After selection of the meals, the adolescents were observed until they finish consuming their meals; the non-edible parts of the meal not consumed by the subjects were then similarly removed from the randomly selected meals. This was to ensure that the duplicate diet really represent the meal consumed by the subjects (Fromme et al., 2007; Van Cauwenbergh et al., 1999). Fruits and pastries, consumed during leisure time activities were also collected by the same method used in collecting the meals (Anke et al., 1991). Solid and liquid meals were collected in separate polyethylene containers. Leak-proof plastic bottles were used for the collection of water and beverages, and plastic containers with covers for collection of solid meals (Lightowler and Davies, 2002). The study population in all three orphanages are given lunch and snack when leaving for school in the morning, after eating breakfast, and therefore subjects did not consume any meal outside the orphanage. The meals were kept in refrigerators until the collection of the last meal for the day, and later transported to the Food Analysis laboratory of the Department of Chemistry, Ghana Atomic Energy Commission, for processing. On each sampling day, a total of 9 sets of duplicate meals including water were obtained from each orphanage. For the one week period, a total of 63 sets of duplicate meals were collected at each orphanage and processed to provide 7 blended lyophilized homogenates of duplicate diets. The detailed recipe and food intake data for Tutu-Akwapim, Osu and Teshie orphanages during the study period are presented in Tables 2, 3 and 4 respectively.

The 9 sets of duplicate meals (including water consumed) collected for a particular day were pooled together to form one composite sample, weighed and homogenized (Lightowler and Davies, 2002; Tripathi et al., 1997; Deutch et al., 2007; Hou et al., 1997). Samples were further homogenized in a blender with Teflon-coated parts (Van Cauwenbergh et al., 1999; Garcia et al., 2001; Robberecht et al., 2002). Two replicate aliquots of about 100 g were taken and frozen at -20°C and lyophilized (Christ, Gamma 1 to 16) at -40°C and 0.120 mbar. This was followed by determination of the lyophilized matter and water contents. The lyophilized samples were pulverized in a vibratory disc mill (Retsch RS 100) to form 21 blended lyophilized homogenate of duplicate diets for all three orphanages. All 21 samples were stored at -20°C in acid-washed plastic bottles with screw caps. The bottles were then placed in hermitically closed polyethylene bags. The samples were later sent by courier to the Jozef Stefan Institute, Ljubljana, Slovenia, for analysis.

Analytical procedure for iodine determination

Analysis of the 21 blended lyophilized homogenates of duplicate diets for their iodine contents was carried out at the Radiochemistry Laboratory of the Department of Environmental Sciences, Jozef Stefan Institute, Ljubljana, Slovenia. The iodine content was determined according to the methods described by Dermelj et al. (1990, 1991), Stibilj et al. (1994) and Osterc and Stibilj (2005).

Instrumentation and other apparatus

Irradiation of samples and standards were carried out in the pnuematic transfer system of Slovenia's Jozef Stefan Institute 250 kW TRIGA Mark II Reactor at a neutron flux of 3.5×10^{12} neutrons cm^{-2} s^{-1}.

Measurement of γ-radiation intensity of ^{128}I ($t_{1/2}$ = 24.99 min; E_γ = 442.9 keV) was performed on a well-type high purity germanium detector (HPGe), connected to a multi-channel analyzer (Canberra). The detector has a resolution of 2.09 keV at the 1332.5 γ-line of ^{60}Co; an efficiency of 51.3% relative to the 1332.5 γ-line of ^{60}Co; and a peak-to-Compton ratio of 59.1.

Digestion of samples was done by combustion in a thick-walled 4 L Schöniger combustion flask fitted with a ground-glass stopper. Attached to the stopper is a platinum gauze basket sample holder. The opening of the flask was tightly fitted with a 2000 ml balloon. An ashless filter paper was used to hold the sample in the platinum gauze basket. Calibrated weighing balances Mettler Toledo AE 163 and AE 240 (Zurich, Switzerland) were used for weighing of chemicals and, radioactive samples and radioactive standards, respectively.

A UV-Visible Spectrophotometer MA 9525-SPECKOL 210 (ISKRA, Slovenia) was used for absorbance measurement in the determination of chemical yield.

Table 2. Recipe and food intake data for Tutu-Akwapim orphanage during the study period.

Day	Meal type	Name of meal	Composition of meal (Ingredients)
1	Breakfast	Corn dough porridge + Koose[a]	Corn, sugar, water, salt, beans, onions, vegetable oil.
	Lunch	Boiled yam + Beans stew	Beans, yam, tomato, pepper, onions, salt, water, palm oil, spices.
	Supper	Boiled rice + Palmnut soup	Rice, palmnut, onions, pepper, tomato, salt, fish.
2	Breakfast	Wheat porridge + Koose[a]	Wheat, sugar, water, salt, beans, onions, vegetable oil.
	Lunch	Boiled rice + Palaver sauce[b] mixed with soya beans	Rice, cocoyam leaves, soya beans, water, palm oil, salt, onions, pepper, tomato.
	Supper	Banku [c] + Groundnut soup	Corn, groundnut, onions, pepper, salt, fish, tomato, water.
3	Breakfast	Corn dough porridge + Koose[a]	Corn, sugar, water, salt, beans, vegetable oil, onions.
	Lunch	Boiled Yam + Palava sauce [b] mixed with beans	Yam, cocoyam leaves, beans, palm oil, onions, pepper, salt, tomato.
	Supper	Boiled Rice + Palaver sauce[b] mixed with soya beans	Rice, cocoyam leaves, soya beans, salt, palm oil, onions, pepper, tomato.
4	Breakfast	Wheat porridge + Koose [a]	Wheat, sugar, water, salt, beans, onions, vegetable oil.
	Lunch	Boiled yam + Palaver sauce [c] mixed with beans	Yam, cocoyam leaves, beans, oil, tomato, pepper, salt, onions.
	Snack	Banana + Groundnut	Banana, groundnut.
	Supper	Banku [c] + Groundnut soup	Corn, groundnut, onions, pepper, salt, fish, tomato, water.
5	Breakfast	Wheat Porridge + Koose[a]	Wheat, sugar, water, salt, beans, onions, vegetable oil.
	Lunch	Boiled Rice + Palaver sauce[b] mixed with soya beans	Rice, cocoyam leaves, soya beans, water, palm oil, salt, onions, pepper, tomato.
	Supper	Banku [c] + Palmnut soup	Corn, palmnut, onions, pepper, salt, fish, tomato, water.
6	Breakfast	Corn dough porridge + Koose[a]	Corn, sugar, water, salt, beans, onions, pepper, vegetable oil.
	Lunch	Banku [b] + Groundnut soup	Corn, groundnut, onions, pepper, salt, tomato, fish, water.
	Supper	Boiled Yam + Palaver sauce[b] mixed with beans	Yam, water, salt, cocoyam leaves, beans, tomato, palm oil, pepper, onion.
7	Breakfast	Wheat porridge + Koose [a]	Wheat, water, sugar, salt, oil, onions, beans, pepper.
	Lunch	Banku [c] + Palmnut soup	Corn, palmnut, onions, pepper, salt, fish, tomato, water, cassava dough.
	Supper	Boiled rice + Palaver sauce [b]mixed with soya beans	Rice, water, salt, cocoyam leaves, pepper, oil, onions, soya beans, tomato.

[a] Koose has milled beans (80%), water (10%), pepper (5%) and salt (5%) as the ingredients. It is prepared by homogenizing the ingredients into a paste. Aliquots of the paste are then fried with cooking oil.[b] Palaver sauce is a stew made from cocoyam leaves (50%), salt, tomato, pepper, onion, spices, sometimes with or without 'Agushi' (that is milled melon seeds), water, palm oil and fish. [c] Banku is made from corn dough (65%), cassava dough (10%), water (20%) and salt (3%). The ingredients are homogenized into a soft paste, and boiled for several minutes with constant stirring into a solid (soft) texture.

Chemicals and reagents

Pure iodine crystals (Riedel-de Haen, Seelze, Germany); cellulose powder (Whatman, England); $NaNO_2$, Na_2SO_3 and NH_4NO_3 (ROTH, Karlsruhe, Germany); KI, KIO_3 and $CHCl_3$ (Merck, Darmstadt, Germany); H_2SO_4, 96%, (Sigma-Adrich); Commercially-available stock NH_3 solution, 25% (Merck, Darmstadt, Germany); ashless filter paper circles (Schleicher and Schuell, Germany); and phase-separating filter paper (Whatman, England).

Deionised water and Milli-Q water produced by Milli-Q equipment (Millipore, Bedford MA, USA) were used. Deionised water was used for preparation of general reagents and Milli-Q water was used for the preparation of 5% NH_3 solution. The following reagents were prepared:

Table 3. Recipe and food intake data for Osu orphanage during the study period.

Day	Meal type	Name of meal	Composition of meal (Ingredients)
1	Breakfast	Sogum porridge + Bread/ Biscuit	Sogum, water, sugar, milk, salt, flour, margarine, yeast.
	Lunch	Boiled rice + Tomato stew + Eggs	Rice, water, onion, tomato, pepper, egg, spices, vegetable oil, salt.
	Supper	Banku [c] + Tomato stew	Corn, salt, water, tomato, onion, pepper, smoked fish, spices cassava dough.
2	Breakfast	Sogum porridge + Bread	Sogum, water, salt, sugar, yeast, milk, margarine, white flour.
	Lunch .	Waakye [d] + Tomato stew+ Boiled egg	Rice, beans, water, salt, tomato, pepper, onion, egg, spices.
	Supper	Boiled rice + Palava sauce [b]	Rice, water, salt, 'kontomire', smoked fish, 'agushi', palm oil, tomato, spices, pepper, onion.
	Snack	Biscuits + Apple juice	
3	Breakfast	Sogum porridge + Bread/ Biscuit	Sogum, water, sugar, milk, salt, yeast, margarine, white flour.
	Lunch	Boiled rice with tomato stew and eggs	Rice, water, salt, onion, tomato, pepper, vegetable oil, egg, spices.
	Supper	Banku [c] + Tomato stew	Corn, salt, water, tomato, onion, pepper, spices, cassava dough fish.
4	Breakfast	Sogum porridge + Bread	Sogum, water, salt, sugar, yeast, milk, margarine, white flour.
	Lunch	Waakye [d] + Tomato stew + Boiled egg	Rice, beans, water, salt, tomato, pepper, onion, egg, spices
	Supper	Boiled rice + Palava sauce [b]	Rice, water, salt, 'kontomire', pepper, fish, tomato, 'agushi', palm oil, spices, onion.
	Snack	Biscuits + Apple juice	
5	Breakfast	Sogum porridge + Biscuits	Sogum, salt, water, milk, sugar, biscuit.
	Lunch	Jollof rice + Chicken	Rice, tomato, vegetable oil, salt, onion, chicken, spices, pepper.
	Supper	Rice balls [e] + Palmnut soup	Rice, palmnut, water, fish, spices, onion, pepper, tomato, salt.
	Snack	Biscuits + Apple/ Orange	
6	Breakfast	Rice porridge + Bread	Rice, water, salt, sugar, yeast, margarine, flour.
	Lunch	Boiled rice + Tomato stew + Boiled egg	Rice, salt, water, tomato, pepper, onion, vegetable oil, egg, spices.
	Supper	Banku [c] + Palmnut soup	Corn, cassava dough, water, salt, palmnut, garden egg, tomato, onion, pepper, fish.
	Snack	Fruit juice + Biscuits	
7	Breakfast	Milo beverage + Bread and beans + Gari [f]	Milo, water, milk, sugar, flour, margarine, palm oil, salt, yeast, beans, gari [f].
	Lunch	Jollof rice + Chicken	Rice, tomato, onion, pepper, salt, vegetable oil, spices, chicken.
	Supper	Banku [c] +Tomato stew+ Boiled fish	Corn, cassava dough, water, salt, onion, pepper, fish, tomato, palm oil, spices.

[d] Waakye is prepared from rice (70%) and beans (30%). The ingredients are boiled for some minutes with water and salt is added to taste. [e] Rice balls are prepared from rice, salt, and water. Rice is boiled for some minutes (till it becomes softer than normal boiled rice). It is then made into small round shape like 'lawn tennis balls'. [f] Gari is cassava flakes.

Table 4. Recipe and food intake data for Teshie orphanage during the study period.

Day	Meal type	Name of meal	Composition of meal (Ingredients)
1	Breakfast	Milo beverage + Bread/ Biscuit	Milo, sugar, water, milk, salt, biscuits, yeast, white flour, salt, margarine, resins.
	Lunch	Banku [c] + Okro stew	Corn, water, salt, tomato, spices, fish, onion, pepper, palm oil, cassava dough, okro, garden egg.
	Supper	Boiled rice + Tomato Stew + Egg	Rice, salt, water, tomato, pepper, onion, eggs, vegetable oil, spices.
2	Breakfast	Corn flakes + Biscuits	Corn, sugar, milk, water, biscuits.
	Lunch	Boiled yam + Garden egg stew	Yam, salt, water, garden egg, tomato, onion, pepper, palm oil, fish.
	Supper	Boiled rice + Tomato + Stew + Boiled egg	Rice, salt, water, egg, tomato, vegetable oil, onion, pepper, spices, oil.
3	Breakfast	Milo beverage + Bread	Brown flour, margarine, yeast, milo, sugar, water, salt.
	Lunch	Waakye [d] + Pepper stew	Rice, beans, salt, water, pepper, tomato, fish, onion, vegetable oil.
	Supper	Banku [c] + Ground pepper and fish	Corn, cassava, salt, water, onion, fried fish, tomato, pepper.
4	Breakfast	Milo beverage + Bread	Milo, sugar, water, milk, flour, margarine, salt.
	Lunch	Banku [c] + Okro Stew	Corn, water, salt, cassava, onion, pepper, palm oil, tomato, fish, meat, spices, okro, garden eggs.
	Supper	Boiled rice with Tomato stew	Rice, salt, water, tomato, pepper, vegetable oil, fish, onion, spices.
5	Breakfast	Corn porridge + Bread	Corn, salt, sugar, flour, yeast, water, margarine.
	Lunch	Boiled yam + Palaver sauce [b]	Yam, salt, water, cocoyam leaves, onion, pepper, palm oil, smoked fish, spices, agushi [g], tomato.
	Supper	Boiled rice + Palava sauce [b]	Rice, salt, water, cocoyam leaves, pepper, onion, palm oil, spices, tomato, smoked fish, agushi [g].
6	Breakfast	Corn flakes + Bread	Corn, milk, sugar, white flour, margarine, yeast, water, salt.
	Lunch	Kpokpoi [h] + Palmnut soup	Corn, palm oil, palmnut, tomato, smoked fish, onion, pepper, meat, water, spices, okro, salt, garden egg, spices.
	Supper	Boiled yam + Palaver sauce [b]	Cocoyam leaves, palm oil, agushi [g], tomato, onion, yam, salt, smoked fish, water, pepper, spices.
7	Breakfast	Oats + Brown bread	Oats, sugar, water, milk, yeast, brown flour, salt, margarine.
	Lunch	Boiled rice + Tomato stew	Rice, water, salt, tomato, meat, onion, pepper, vegetable oil, spices.
	Supper	Ga kenkey [i] + Pepper + Fried fish	Corn, salt, water, tomato, pepper, vegetable oil, onion, fish.
	Snack	Orange	

[g] Agushi is milled melon seeds. [h] Kpokpoi is prepared from milled corn, palm oil, onion, and spices. It is prepared by mixing steamed milled corn (90%) with pre- warmed palm oil (10%). [i] Ga kenkey is prepared from milled corn dough, salt, and water. It is prepared by pre-boiled milled corn dough with added salt. It is then laced in special leaves and boiled for some hours.

Table 5. Chemical yield of iodine compared with literature data.

Material	Separation technique	Digestion	Extractant	Chemical yield of Iodine		Reference
				Measurement technique	Chemical yield (%)	
Biological	I_2 extraction	O_2 combustion	$CHCl_3$	Spectrophotometry	83-88	Present study
Biological	I_2 extraction	O_2 combustion	CCl_4	Spectrophotometry	85-95	Dermelj et al. (1991)
Biological	I_2 extraction	Alkaline fusion	$CHCl_3$	^{131}I Radiotracer	90-95	Kucera et al. (2004)
Biological	AgI precipitate	Alkaline fusion	-	Gravimetry	80-95	Kucera et al. (2001)
Biological	I_2 extraction	O_2 combustion	$CHCl_3$	Spectrophotometry	75-82	Osterc and Stibilj (2005)
Biological	I_2 extraction	Alkaline fusion	$CHCl_3$	-	90-95	Akhter et al. (2004)
Water	I_2 extraction	-	CCl_4	Radiotracer	92-97	Dermelj et al. (1991)
Biological	I_2 extraction	O_2 combustion	CCl_4	Radiotracer	89 ± 5	Dermelj et al. (1991)

O_2 combustion is the same as Schoniger combustion. I_2 extraction refers to classical oxidation-reductive stripping-oxidation using $NaNO_2$ and Na_2SO_3.

A 10% $NaNO_2$ solution was used together with 2.5 M H_2SO_4 for oxidation of iodide to iodine. A 2.5 M H_2SO_4 solution was used together with 10% $NaNO_2$ for the oxidation of iodide to iodine. A 0.05 M H_2SO_4 solution was used as an absorbing solution. An aliquot of this solution was placed in the Schöniger combustion flask prior to sample combustion. The gaseous iodine liberated during combustion was quantitatively absorbed and retained in this solution after combustion. 10% Na_2SO_3 solution was used for the reduction of iodine to iodide. A 5% NH_3 solution, prepared from commercially-available 25% NH_3 solution, was used for the preparation of iodine standards.

Standards

Three iodine standards were prepared; a 10 µg g^{-1} working standard prepared in 5% NH_3 solution; a 50 mg g^{-1} carrier solution prepared in 5% NH_3, and a 200 µg ml^{-1} working standard prepared in chloroform. After preparation, all the standard solutions (stock and working solutions) were stored in the dark.

A stock standard solution containing 1 mg g^{-1} in 5% NH_3 Solution was prepared by dissolving 0.2254 g of oven-dried (at 120°C) KIO_3 powder in 5% NH_3 and diluting to volume with 5% NH_3 in a 100 ml volumetric flask. A working standard containing 10 µg g^{-1} was prepared by appropriate dilution of the stock. This working standard solution was not subjected to chemical treatment. An appropriate aliquot of this standard was always irradiated together with the sample.

A 50 mg g^{-1} in 5% ammonia solution carrier solution was prepared by dissolving 3.2728 g of KI in 5% NH_3, and diluting to volume with 5% NH_3 in a 50 ml volumetric flask. The carrier solution was used to ensure identical separation conditions and allow the chemical yield of iodine separations to be determined. About 100 mg aliquot of this standard was added to the radioactive sample just before sample decomposition.

A stock solution containing 1 mg ml^{-1} in $CHCl_3$ was prepared by dissolving 0.25 g of pure iodine crystals in $CHCl_3$ and diluting to volume with $CHCl_3$ in a 250 ml volumetric flask. A working standard containing 200 µg ml^{-1} $CHCl_3$ was prepared daily from appropriate dilution of the stock. The working standard was used for the determination of chemical yield (recovery) of iodine by spectrophotometry. A National Institute of Standards and Technology standard reference material, NIST SRM 1548a (Typical diet) was used to check the validity of the RNAA method for iodine determination.

Radiochemical neutron activation analysis

The procedure involves irradiation of samples and standards, organic matter destruction, separation of iodine, γ-activity measurement and chemical yield determination. The detailed procedure is as follows: An aliquot (200 to 250 mg) of the blended lyophilized and homogenized duplicate diet with an appropriate aliquot of iodine standard (10 µg g^{-1}) in the same irradiation capsule were simultaneously irradiated for 1 min. Immediately, the sample and standard were ejected from the reactor, the radioactive sample was mineralized by Schoniger combustion using pure oxygen and NH_4NO_3, with dilute H_2SO_4 as absorbing solution. After combustion the absorbing solution was quantitatively transferred into a 150 mL separatory funnel for separation of the ^{128}I radionuclide. Iodine was separated by solvent extraction through classical oxidation-reductive stripping-oxidation cycle using $NaNO_2$ and Na_2SO_3 Chloroform ($CHCl_3$) was used as extractant. After separation, the $CHCl_3$ extract was transferred into a 10 ml γ-counting vial, and the γ-activity of the separated ^{128}I measured for 25 min.

This was followed by measurement of the γ-activity of the induced radionuclide ^{128}I in the standard iodine solution irradiated together with the sample. The GENIE 2000 γ-spectrum acquisition software was used for γ-spectrum acquisition. After γ-spectrum acquisition for $CHCl_3$ extract (sample) and working iodine standard, their respective net peak areas were evaluated at the 442.9 keV γ-energy of ^{128}I. The quantification was done using the HPGe semi-conductor detector γ-spectrum evaluation software, HYPERMET, (Version 5.0, Institute of Isotopes, Budapest,

Table 6. Iodine content in NIST SRM 1548a (Typical diet).

Material	Mass fraction of iodine (ng g^{-1} dry $matter^{-1}$)			Reference for literature data
	This work	Certified	Literature	
NIST 1548a	718 ± 27 (8) (RNAA)	745 ± 103 (RNAA; PCNAA)	713 ± 57 (5) (ENAA-CSC)	Kucera et al. (2004)
			641 ± 44 (3) (ENAA)	Adrasi et al. (2007)

Data are presented as mean ± standard deviation (number of measurements) (Measurement technique).

Hungary).

Chemical yield of radiochemical separation

The chemical yield of iodine in the radiochemical separation was established by differential spectrophotometry. After γ-activity measurement, the $CHCl_3$ extract was filtered through a phase-separating filter paper and quantitatively transferred to a 25 ml volumetric flask and diluted to volume with $CHCl_3$. An appropriate aliquot of the dilute $CHCl_3$ extract was transferred into a 1 cm quartz glass cuvette (HELLMA, Germany), and the absorbance at a wavelength of 517 nm and slit width of 5 nm measured. The absorbance of an appropriate aliquot of the working iodine standard in chloroform (200 µg ml^{-1} $CHCl_3$) was also measured using the same cuvette and at the same wavelength and slit width. The chemical yield was evaluated by comparing the absorbance of the $CHCl_3$ extract and that of the iodine standard. The chemical yield was used in correcting for iodine mass loss during the separation in order to obtain the correct mass fraction of iodine in the duplicate diet. A comparison of the chemical yield obtained in this study with chemical yields quoted in literature is presented in Table 5. The chemical yields of iodine for the 42 radiochemical separations (that is 2 replicate measurements for each of the 21 lyophilized homogenate of duplicate diets) ranges from 83 to 88%. The chemical yield of iodine obtained in the present study is in good agreement with chemical yields quoted in literature.

Validation of RNAA method

The validity of the RNAA for iodine determination was checked by analyses of compositionally similar standard reference material, NIST SRM 1548a (Typical Diet). The results obtained are in good agreement with the certified value and comparable to literature data (Table 6).

RESULTS AND DISCUSSION

The adolescent diets

The adolescents in all three orphanages consume three daily rations (breakfast, lunch and dinner) and all meals consumed (including beverages) were made up of meals typical in the Ghanaian diet. At least twice a day meals (mostly lunch and supper) for the 7-consecutive days in the orphanages were prepared from rice, maize, beans, yam, marine fish, egg, cassava, onion, tomato, pepper, vegetable oil, palm oil, iodated salt, spices and soya beans. Beverages had milk, sugar, bread made from white flour, local bread made from milled beans, iodized salt and maize, as the ingredients (Tables 2, 3 and 4). Cooking methods employed by the kitchen staff of the orphanages during the sampling period consisted of frying (shallow and deep), baking, roasting, boiling and steaming.The main sources of iodine in Ghanaian diets are marine fish and iodized salt. Ghana requires mandatory iodisation of salt (20 to 40 mg iodine/kg salt) using KIO_3 as the fortificant (ICCIDD, 2007). Marine fish is a major ingredient in most traditional Ghanaian diets. Marine fish has been identified as the richest source of iodine for humans (El-Ghawi and Al-Sadeq, 2006; Haldimann et al., 2005). Milk can be a significant contributor of iodine to the daily diet, although its content can be quite variable depending on the iodine content in animal feeds (El-Ghawi and Al-Sadeq, 2006).

The normal cooking procedure for preparing most traditional beverages (for breakfast) involves heating the appropriate quantity of water till it boils, followed by the addition of the main ingredient (the main ingredient is added as a paste; after homogenisation of the main ingredient by forming a paste with water). It is boiled for about 25 to 30 min with constant stirring at and above 100°C, during this period, iodated salt is added, then later sugar and milk are added to taste. Cooking practices for preparing the traditional Ghanaian soups and stews are boiling and frying of the ingredients for 45 to 90 min and 30 to 60 min, respectively at and above 100°C. Iodine is volatile at temperatures of 58°C (El-Ghawi and Al-Sadeq, 2006), consequently boiling at and above 100°C will lead to loss of appreciable amounts of iodine during the preparation of meals depending on the boiling temperature and duration of boiling.

Mass fraction of iodine in food duplicates

Mass fractions of iodine, determined in the adolescent total diets for the 7-consecutive days in the three orphanages (Osu, Tutu-Akwapim and Teshie), are presented on Table 7. Day 1 to 7 represents Monday to Sunday, respectively.

For Tutu-Akwapim, the mass fraction of iodine varied from 205 (Day 6) to 350 ng g^{-1} (Day 5). The variation in

Table 7. Mass fraction of iodine.

Mass fraction of Iodine, (ng g^{-1} lyophilized matter)			
Day of the week	**Osu**	**Tutu-Akwapim**	**Teshie**
Day 1	379 ± 18	263 ± 7	1315 ± 5
Day 2	274 ± 18	339 ± 16	595 ± 7
Day 3	335 ± 2	209 ± 7	789 ± 32
Day 4	254 ± 5	338 ± 1	1728 ± 38
Day 5	235 ± 8	350 ± 36	881 ± 3
Day 6	210 ± 4	205 ± 4	685 ± 30
Day 7	319 ± 7	293 ± 12	733 ± 11
Mean mass fraction	287 ± 95	286 ± 109	961 ± 142
Range	(206 - 397)	(201 - 386)	(588 - 1766)

Data on daily mass fraction of iodine are presented as Mean ± average absolute deviation, data on mean mass fraction of iodine are presented as Mean ± standard deviation.

the day-to-day mass fraction of iodine may be due to the different composition of the meals, though there were similarities. Interestingly, the mass fractions of 205 and 209 ng g^{-1} for Days 6 and 3, respectively were almost the same. A critical look at the meals consumed on Day 3and Day 6 (Table 2) shows that the same type of meals with the same composition were taken during breakfast on both days. Secondly, the type of meal taken at lunch on Day 3 was the same as the meal taken at supper on Day 6. Consequently, the compositions of the meals were the same. These factors may have accounted for the interesting observation. The mass fraction of iodine in the meals for Days 2 and 4, with mass fractions of 339 and 338 ng g^{-1} respectively were the same. This may be due to the consumption of the same types of meals with the same compositions during breakfast, lunch and supper (Table 2).

There was a significant variation in the day-to-day mass fraction of iodine in the adolescent total diet from Osu. The mass fraction of iodine varied from 210 (Day 6) to 379 ng g^{-1} (Day 1). The variation in the mass fraction of iodine throughout the one-week period might be due to the composition of the meals for the period, the use of fish in the preparation of the meals. The presence of iodine in adolescent diets is dependent on fish consumption (Fecher et al., 1998). The mass fractions of 274 (Day 2) and 254 ng g^{-1} (Day 4) did not vary significantly. This could be attributed to the consumption of the same meals with similar composition during breakfast, lunch and supper (Table 3). There was no marked variation in the mass fraction of 335 (Day 3) and 319 ng g^{-1} (Day 7). This may be attributed to the compositionally similar nature of the meals consumed during lunch on both days. In addition, the same types of meals with the same compositions were consumed during supper on both days (Table 3).

The mass fraction of iodine in the adolescent total diet for Teshie during the 1-week period showed a significantly high variation. The mass fraction varied from 595 (Day 2) to 1728 ng g^{-1} (Day 4). The significantly high mass fractions of iodine at Teshie during the 1-week period compared with the other two orphanages may be attributed to the high consumption of marine fish at Teshie. The coastal town of Teshie is predominantly a marine fishing community and the sampling period of August and September is the peak of the fishing season in Ghana. Consequently, marine fish consumption within the Teshie community during the fishing season is very high, because the price of fish is affordable. Analyzing the composition of the meals critically shows fish as an ingredient in the meals prepared on each day (Table 4). Marine fish is the richest source of iodine for humans (Haldimann et al., 2005). The high mass fractions of (Day 1) and 1728 ng g^{-1} (Day 4) varied significantly from the other days. This could be attributed to the consumption of the same type of meals during breakfast, lunch and supper. The compositions of the meals for the two days (Day 1 and 4) were similar (Table 4).

The mean mass fraction of iodine for Osu, (287 ± 95 ng g^{-1}), and Tutu, (285 ± 109 ng g^{-1}), are similar. However, the mean mass fraction of iodine for Teshie, (961 ± 142 ng g^{-1}), was significantly high.

Dietary intake of iodine

The detailed results of the evaluated dietary intake of iodine for the studied orphanages are presented in Table 8. The dietary intake of iodine (µg day^{-1}) in the 24 h duplicate diet was calculated based on the measured mass fraction of iodine (µg g^{-1}) and the lyophilized matter content of the food consumed per person per day (g day^{-1}).

Table 8. Dietary intake of iodine for the orphanages.

Dietary intake of Iodine (µg day^{-1})			
Day of the week	**Osu**	**Tutu**	**Teshie**
Day 1	141 ± 7	105 ± 3	414 ± 2
Day 2	122 ± 8	144 ± 7	191 ± 2
Day 3	97 ± 1	91 ± 3	280 ± 11
Day 4	79 ± 2	125 ± 1	554 ± 12
Day 5	83 ± 3	131 ± 13	297 ± 1
Day 6	76 ± 2	75 ± 2	290 ± 13
Day 7	114 ± 2	129 ± 5	352 ± 5
Mean dietary intake	102 ± 25	115 ± 25	340 ± 117
Range	(74-148)	(74 - 151)	(189 - 566)

Data on daily dietary intake of iodine are presented as Mean ± average absolute deviation, data on mean dietary intake of iodine are presented as Mean ± standard deviation.

Table 9. Comparison of dietary intake of iodine with literature data.

Country	Study population	Dietary Intake (µg.day^{-1})	Sampling/ (Measurement) technique	Reference
Ghana (Osu)	12-15 years	102 ± 25	DD/ (RNAA)	This work
Ghana (Tutu)	12-15 years	115 ± 25	DD/ (RNAA)	This work
Ghana (Teshie)	12-15 years	340 ± 117	DD/ (RNAA)	This work
China	General	364	DD/ (RNAA; ENAA)	Parr et al. (2005)
Libya	General	100-180	MB/ (ENAA)	El-Ghawi and Al Sadeq (2006)
Iran	General	114	DR/ (RNAA; ENAA)	Gharib et al. (2001)
India	General	106	DD/ (ENAA; RNAA)	Parr et al. (2005)
Pakistan	General	60	TCD/ (RNAA)	Iyengar et al. (2002)
Turkey	General	90	MB/ (ENAA)	Parr et al. (2005)
Sudan	General	90	DD/ (ENAA)	Parr et al. (2005)
Switzerland	General	140	MB/ (ID-ICPMS)	Haldimann et al. (2005)
Brazil	General	250	DD/ (ENAA)	Parr et al. (2005)
UK	General	250	TDS/ (ICPMS)	Rose et al. (2001)
Philippines	General	119	MB, DD/(ENAA, RNAA)	Parr et al. (2005)

TDS - Total diet study, DD- duplicate diet), MB- market basket), TCD- total cooked diet and DR- dietary records.

There was significant variation in the day-to-day dietary intake of iodine over the 7-consecutive days at Tutu. However, there was no significant difference between the dietary intakes of 125, 131 and 129 µg day^{-1} for Days 4, 5 and 7, respectively. This interesting trend may be attributed to the compositionally similar nature of the meals for these days (Table 2). The similar composition of the meals consumed on Days 1 and 3 (Table 2) may also have accounted for the close dietary intakes of 105 and 91 µg day^{-1} respectively.

There was a marked variation in the dietary intake of iodine by adolescents living in Osu Children's Home. However, the dietary intakes of 122 and 114 µg day^{-1} for Days 2 and 7, respectively did not vary significantly though the composition of the meals for these days were not too similar (Table 3). The dietary intakes of 79 (Day 4), 83 (Day 5) and 76 µg day^{-1} (Day 6) did not also show any significant variation. This trend may be due to the similar composition of the meals though the meal types were different (Table 3).

The daily dietary intake of iodine by Teshie adolescents varied from 191 to 554 µg day^{-1}. The dietary intake of 554 µg day^{-1} (Day 4) varied from the dietary intake of 191 µg day^{-1} (Day 2) by a factor of 3. The high variability in the dietary intake of iodine during the 1-week period reflects differences in fish consumption. There was no significant difference in the dietary iodine intake of 280 (Day 3), 297 (Day 5) and 290 µg day^{-1} (Day 6). This may be attributed to the similar fish consumption pattern on these days (Table 4). Fish was part of both lunch and supper on

these days.

Comparison of dietary intake with literature data and RDA for iodine

The average dietary intake of iodine for Osu (102 ± 25 µg day^{-1}) and Tutu (115 ± 25 µg day^{-1}) though slightly lower than the RDA of 150 µg day^{-1} (Institute of Medicine, 2001), are within the 100 to 150 µg day^{-1} normal iodine intake for non-iodine deficient countries of the world (Hassanien et al., 2003). The dietary intake of iodine for Osu and Tutu are comparable to iodine intake quoted in literature in similar nutritional studies for the Philippines, Libya, India and Iran (Table 9). The average dietary intake of 340 ± 117 µg day^{-1} for Teshie was significantly higher (variation factor of 2) than the RDA of 150 µg day^{-1} (Institute of Medicine, 2001). However, the evaluated dietary intake for Teshie is comparable to the dietary intake of 364 µg day^{-1} found in literature for the general population of China (Table 9). The evaluated dietary intake of iodine for the three orphanages could not be compared with literature data for adolescents, therefore the dietary intakes was compared with literature data for the general population of other countries. This is because data on the uptake of iodine by adolescents are extremely rear and practically does not exist.

Conclusion

The importance of dietary iodine for normal growth and development, both mental and physical, is widely accepted. In the present study, analysis of the duplicate diets showed a wide variation in iodine intake. Although, the daily iodine intakes by Osu adolescents (102 µg day^{-1}) and Tutu adolescents (115 µg day^{-1}) were slightly lower than the RDA of 150 µg day^{-1}, they were within the normal iodine intake of 100 the 150 µg day^{-1} in non-iodine deficient countries of the world. The dietary intake of iodine by the adolescents compares favourably with reported values in scientific literature for other countries in similar nutritional studies. The study has also provided nutritional information on the background iodine levels in the 24 h duplicate diet of the adolescents living in the studied orphanages. Data from dietary intake assessments are important for planning institutional diets and for developing sound nutritional policies in a country. The data generated will help nutritionist and health professionals in developing sound nutritional policies for the orphanages.

ACKNOWLEDGEMENT

The authors thank the International Atomic Energy Agency (IAEA) for supporting the study financially. The authors wish to thank personnel of the Department of Environmental Sciences, Jozef Stefan Institute, Ljubljana, Slovenia, for their support during sample analysis. The skilled technical assistance of Messers B. Q. Modzinuh and Nicholas Opata, Ms. Gladys Adjei-Mantey and Ms. Beatrice Blewu, during sample preparation at the Ghana Atomic Energy Commission, are gratefully acknowledged.

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