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Studying iodine intake of Portuguese children school meals

Inês Delgado [a,b], Marta Ventura [a,c], Sandra Gueifão [a,b], Ricardo Assunção [d], Inês Coelho [a,b], Alexandra Bento [a], José Armando L. Silva [e,*], Isabel Castanheira [a,c,*]

[a] Departamento de Alimentação e Nutrição, Instituto Nacional de Saúde Doutor Ricardo Jorge, INSA. IP, Avenida Padre Cruz, 1649-016 Lisboa, Portugal
[b] Departamento de Engenharia Química, Instituto Superior Técnico, Av. Rovisco Pais, 1049-001 Lisboa, Portugal
[c] MARE - Marine and Environmental Sciences Centre, Department of Environmental Sciences and Engineering, NOVA School of Science and Technology (FCT NOVA), University NOVA of Lisbon), 2829-516 Caparica, Portugal
[d] IUEM, Instituto Universitário Egas Moniz, Egas Moniz - Cooperativa de Ensino Superior, CRL, Quinta da Granja, Monte de Caparica, 2829-511 Almada, Portugal
[e] Centro de Química Estrutural, Institute of Molecular Sciences, Departamento de Engenharia Química, Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais, 1049-001 Lisboa, Portugal

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ABSTRACT

Iodine is an essential trace element, and its nutritional importance is well established. The iodine content of school meals of Portuguese children aged between 6 and 10 years (collected in the metropolitan area of Lisbon) was analyzed by ICP-MS. The samples were cooked with and without iodized salt and additionally some complementary foods were purchased as supplements to the main meals or to the other meal along the day. The results report six meals per day and they suggest that at least one main meals (lunch or dinner) prepared with iodized salt is enough to reach the recommended daily iodine intake (AI), 90 µg/day, not exceeding the tolerable upper intake (UL) level of 300 µg/day. When both main meals are cooked without iodized salt, 11 % of the hypotheses present an iodine content less than 90 µg/day. However, when lunch and dinner are prepared with iodized salt, 1 % exceeds the value of the UL. The food groups with the highest levels of iodine are daily products and fish. These results presuppose a balanced diet without any dietary restrictions. So, for ideological or medical reasons, special attention must be paid to diets with some limitations, such as vegetarian, lactose or high content of proteins free diets.

1. Introduction

Iodine is a micronutrient essential for the correct functioning of the thyroid, since is a constituent of its hormones (Rohner et al., 2014). An inadequate intake of iodine leads to iodine efficiency disorders (IDD) such as goiter, and its deficiency can provoke in case of pregnancy to the newborn, as well as to school-age children, impaired brain development and, therefore, a reduction in mental function (Zimmermann, 2012). Mild to moderate iodine deficiency was reported in several countries, corresponding to an one quarter (in a total of 128 countries) with a significant deficiency (Zimmermann, 2013; Zimmermann and Andersson, 2012). In Portugal, previous studies indicated a widespread of iodine deficiency in pregnant women, lactating women and school-age children. This was identified with more prevalence in Azores and Madeira archipelagos as compared with mainland (Costa Leite et al., 2017; Limbert et al., 2010, 2012; Zimmermann and Andersson, 2011).

Recent studies show that iodine deficiency in school-age children is typically related to low milk consumption, although, it is not so relevant when fish is a component of meals, even for low level of consumption (Costa Leite et al., 2017). Animal based foods, mainly if they are from the sea, are the most common natural source of iodine for humans, and their levels are often related to the contents and bioavailability of this chemical element in soils (relevant to mammals producers of milk for human consumption) and the seas where the sources of food are grown or produced (Rohner et al., 2014); otherwise, the addition of a complement of iodized salt in the preparation of food is an alternative source of iodine that it could overcome iodine deficiency (Rohner et al., 2014). To supress iodine deficiency in the most vulnerable population groups, pregnant women and school-age children, the World Health Organization (WHO) recommends the use of iodized salt instead of normal salt, as a supplement for these groups (World Health Organisation, 2007). Thus, in the case of school-age children, in 2013 the Portuguese Directorate-General for Education (DGE) made use of iodized salt mandatory in the preparation of meals in school canteens (Direção-Geral

* Corresponding authors.
E-mail addresses: pcd1950@tecnico.ulisboa.pt (J.A.L. Silva), isabel.castanheira@insa.min-saude.pt (I. Castanheira).

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da Educação, 2013). However, to follow WHO recommendations, high accurate food analytical data required to determine the content of consumed iodized salt (Delgado et al., 2018), thus, avoiding overdose levels, which can produce health disorders, as impaired mental function and other neurodevelopment diseases, delayed physical development and iodine-induced hyperthyroidism (World Health Organisation, 2007; Zimmermann, 2013).

Furthermore, the variability of iodine contents among the same group of food (Rohner et al., 2014), quality of analytical data and shortage of food consumption data contribute to disagreements surrounding iodine requirements for target population groups (Pehrsson et al., 2016). Therefore, estimation of iodine intake using chemometric tools combining with data supported in metrological instruments (Rychlik et al., 2018) can be a helpful methodology to find a more efficient procedure to surpass this situation.

Based on this context, meals of schools (with children aged between 6 and 10 years) of the metropolitan area of Lisbon, were analyzed to monitor the real content of iodine in school meals in Portugal, covering more than three thousands of children; additionally, some snacks were purchased to complement all meals of the day.

This study provides pattern scenarios in which the iodine foods/iodization salt is an advisable strategy to reduce iodine disorders. Furthermore, the modelling is a tool for supporting health professionals and policymakers to establish nutrition-related policies using best cooking practices combining the national iodine food composition data with food consumption data. Finally, this study can also assist those at the borderline of iodine shortage; individuals and ethnic groups adopting diets exclude or restrict iodine-rich sources such as low salt diets and vegetarian diet patterns.

Based on these results the intake of iodine by this age group was estimated. The obtained data can be used to understand and improve the health levels in Portugal.

2. Materials and methods

2.1. Sampling plan

All samples used in these work were collected following a sampling plan representative of the Portuguese diet, as outlined in the Total Diet Study Exposure project (Dofkova et al., 2016; Fabrice Elegbede et al., 2017). One laboratory sample (pool) was composed od 12 identical foods. In order to represent the consumption of the Portuguese population, a pool may consist of different types of cooking, different brands or cultivars.

2.1.1. Samples of foods cooked with iodized salt

Samples were collected from primary schools located in the metropolitan area of Lisbon, which voluntarily agreed to participate in this project, representing more than 3000 children. The school canteen suppliers of this study represent around 70 % of the schools in the Lisbon metropolitan area. They are representativeness of the Portuguese reality due to the high percentage of users of canteens and a level of schooling in this age is ca. 100 %. A sampling plan was designed taking into account the representativeness and importance of the addition of iodized salt in the preparation of the main meals. The collection of food samples from the menu was carried out in canteens during the school year 2016–2017. The samples were collected after analyzing the menus of the various school and evaluating meals most often available. A total of 144 samples were collected: vegetable soup, pulses soup, pasta, rice, vegetable rice (containing e.g., peas, tomato, carrot, beans), potatoes, minced beef, pork, chicken, turkey, hake, and cod.

2.1.2. Samples of foods cooked without iodized salt and samples of foods consumed as purchased

The effectiveness of the usage of the iodized salt in schools canteens were evaluated and compared with data from a previous general study reporting iodine content of Portuguese foods (Delgado et al., 2018) where equivalent samples were cooked without iodized salt. Other samples that are consumed as they were purchased, such as bread, cheese, ham, milk, yogurt, breakfast cereals and fruit, in supermarkets of the same region, following the sampling plan methodology of the TDS Exposure project (Delgado et al., 2018).

2.2. Sample preparation by iodine analysis

The iodine content was determined by ICP-MS, with reference to EN 15111:2007 (European Committee for Standardization, 2007). Laboratory sample preparation was performed as described before (Delgado et al., 2019). Briefly samples were grouped into pools of 12 samples composed of identical foods. Subsequently, pooled samples were homogenized and approximately 0.5000 g each one (4.00 mL of mixture) were transferred to 50 mL tubes. A pretreatment was carried out to all starchy samples, before tetramethylammonium hydroxide TMAH extraction samples were subjected overnight with a 1.5 % pancreatin from porcine pancreas solution at 37 °C to minimize the formation of starch clumps during extraction of iodine. Then, it was added 1.00 mL of TMAH 25 % v/v (Fluka, Honeywell, Bucharest, Romania) and finally completed until 8.00 mL with ultra-pure water level I obtained from a Milli-Q Element system (Millipore Corporation, Saint-Quentin, France). After an efficient iodine extraction in a graphite block system during 3 h at 90 °C, samples were centrifuged and filtered through 0.45 μm syringe filters.

2.3. Instrumentation

Iodine was determined by an inductively coupled plasma mass spectrometer (ICP-MS), Thermo X series II, equipped with autosampler Cetac ASX-520. Instrumental settings of ICP-OES were specified in previous work (Delgado et al., 2019). Measurements were performed using software Xseries PlasmaLab 2.5.

2.4. Quality control

The complete procedure (purchase up to analysis) complied with EuroFIR requirements to guarantee that data score the highest index to enter in Food Composition Databank and used at global level (Rychlik et al., 2018; Shewry et al., 2009; Vellinga et al., 2022). Analytical results were obtained under quality assurance conditions and in triplicate supported by the requirements described in NP ISO/IEC 17025:2017 (European Committee for Standardization, 2018). The quality assurance conditions described in previous works (Delgado et al., 2018, 2019). Iodine was quantified with a calibration curve with six points, with a correlation coefficient of ≥ 0.9995 and using an internal quality control. To monitor the matrix effects an internal standard was added, and only results in the range between 70 % and 130 % were accepted, as is previously reported (Delgado et al., 2019). To ensure the analytical quality the precision and accuracy, limit of quantification (LoQ), selectivity, and an effective internal and external quality control program [Certified Reference Materials (CRM), spiked samples and Proficiency Testing (PT) Schemes] were carried out. More results of quality control for iodine determination was showed in Table 1.

2.5. Risk-benefit approach

2.5.1. Calculations

All the calculations were performed using Microsoft® Excel spreadsheets. The results of the iodine content in foods consumed as purchased and cooked with and without iodized salt (μg/100 g) are summarized in the Table 2, where Mean, Standard Deviation, Limit of Detection and Limit of Quantification for all the samples analyzed are presented. Samples were divided into three categories, foods consumed as purchased (7 laboratory samples), foods cooked without iodized salt (11

Table 1
Results of quality control for iodine determination.

Matrix	SRM/CRM/QCM	Certified/ Indicative value	Observed Value	Z-score
Infant Formula (mg/Kg)	FAPAS 07435	1.1	1.1	-0.25
Ham (µg/Kg)	BIPEA 9–2432–0012	906	813	-0.59
Soup (µg/Kg)	Spike	67	73	-0.45
Rice (µg/Kg)	Spike	158	184	-0.82
Hake (µg/Kg)	Spike	661	712	-0.39

SRM – Standard Reference Material; CRM- Certified Reference Material; QCM – Quality Control Material

Table 2
Results of the iodine content in food samples (µg/100 g).

		Mean	SD[1]	Mean ± SD	LoD[2]	LoQ[3]
Food consumed as purchased	Bread	0	0	0 ± 0	0.25	0.82
	Cheese	39	2	39 ± 2	0.19	0.74
	Ham	3.3	0.1	3.3 ± 0.1	0.46	1.8
	Milk	23.0	0.1	23 ± 0.1	0.30	0.93
	Cereals	0.85	0.06	0.85 ± 0.06	0.25	0.82
	Fruit	0	0	0 ± 0	0.45	1.7
	Yogurt	17.9	0.1	17.9 ± 0.1	0.08	0.30
Foods cooked without iodized salt	Soup	0.67	0.02	0.67 ± 0.02	0.10	0.31
	Pasta	0	0	0 ± 0	0.25	0.77
	Rice	0	0	0 ± 0	0.25	0.77
	Vegetable Rice	1.3	0.1	1.3 ± 0.1	0.25	0.77
	Potato	0	0	0 ± 0	0.11	0.34
	Chicken	2.4	0.2	2.4 ± 0.2	0.63	2.0
	Turkey	0	0	0 ± 0	0.65	2.0
	Minced Beef	6.6	1.2	6.6 ± 1.2	0.62	1.9
	Pork	0	0	0 ± 0	0.65	2.0
	Hake	9.7	0.3	9.7 ± 0.3	0.54	1.9
	Cod	20	1	20 ± 1	0.18	0.60
Foods cooked with iodized salt	Soup	25	4	25 ± 4	0.10	0.31
	Pasta	0	0	0 ± 0	0.25	0.77
	Rice	29	1	29 ± 1	0.25	0.77
	Vegetable Rice	26	2	26 ± 2	0.25	0.77
	Potato	19	2	19 ± 2	0.11	0.34
	Chicken	18	1	18 ± 1	0.63	2.0
	Turkey	25.0	0.2	25 ± 0.2	0.65	2.0
	Minced Beef	28	2	28 ± 2	0.62	1.9
	Pork	16	1	16 ± 1	0.65	2.0
	Hake	28	1	28 ± 1	0.54	1.9
	Cod	27	2	27 ± 2	0.18	0.60

[1]SD – Standard Deviation; [2]LoD – Limit of Detection; [3]LoQ – Limit of Quantification

laboratory samples), and foods cooked with iodized salt (11 laboratory samples).

Mean consumption for each type of considered foods was extracted from the Portuguese National Food, Nutrition and Physical Activity Survey (IAN-AF) (Lopes et al., 2017), presented in Table 3. To estimate the daily iodine intake, consumption values were multiplied by iodine content for each food type.

Taking into account this information, several hypotheses were considered for each group of the meals based on different combinations of foods, a varied diet and considered suitable for a child. Three hypothetical scenarios for one day included the following meals: breakfast, morning snack, lunch, afternoon snack, dinner and evening meal; Scenario 1, lunch and dinner were cooked without iodized salt; Scenario 2, lunch was cooked with iodized salt, but not dinner; and, Scenario 3, both lunch and dinner were cooked with iodized salt.

Table 3
Mean consumption of studied foods to children. Data from IAN-AF 2015–2016.

Food	Consumption (g/day)
Bread	78.5
Cheese	31.3
Ham	30.7
Milk	366
Cereals	36.4
Fruit	136
Yogurt	175
Soup	315
Pasta	83.1
Rice	114
Vegetable Rice	114
Potato	95.4
Chicken	74.2
Turkey	74.2
Minced Beef	74.8
Pork	74.8
Hake	55.4
Cod	55.4

These were coded considering the type of meal and the number of possible combinations for each one. Hence, Breakfast was used Bx, for the Morning Snack MS1, Lunch – Ly, Afternoon Snack – ASx, Dinner – Dy and Evening Meal – EM1, where the range of x varies from 1 to 3, while y between 1 and 24, possible combinations between foods from Table 4.

For each scenario, 5184 hypotheses of dietary day were created. The estimated iodine content for each hypothesis was obtained by the sum of all foods consumed on the hypothetical day.

It was assumed, for the calculations, that the samples with values below the limit of quantification (LoQ), have a negligible contribution.

2.5.2. *Recommended nutrient intake*

The recommended daily iodine intake (AI) is 90 µg/day and the tolerable upper intake (UL) level is 300 µg/day for children, as indicated by (European Food Safety Authority, 2006, 2014).

3. Results and discussion

The results were obtained taking into account a diet without food restrictions. Therefore, dietary patterns excluding animal based foods were not including in these scenarios.

The results of the iodine content in food samples were presented in Table 2. Plant based foods were without processing had the lowest levels of iodine, namely fruits whose its values were not possible to quantify;

Table 4
Hypotheses of meals for one day.

	Food	Number of hypotheses
Breakfast (B)	Bread, cheese, ham, milk, cereals	3
Morning snack (MS)	Fruit	1
Lunch (L)	Soup, pasta, rice, vegetable rice, potato, chicken, turkey, minced beef, pork, hake, cod, fruit	24
Afternoon snack (AS)	Bread, ham, fruit, yogurt, milk	3
Dinner (D)	Soup, pasta, rice, vegetable rice, potato, chicken, turkey, minced beef, pork, hake, cod, fruit	24
Evening meal (EM)	Milk	1

similarly, bread presented values bellow limit of quantification, since the salt added to its production was not enriched in iodine. These results are not a surprise since it was previously reported (Dahl et al., 2004; Haldimann et al., 2005). On the other hand, within this type of food, breakfast cereals contained a quantifiable value but it was very close to LoQ; their higher contents may be due to the fact that ingredients from animal origin, such as milk, were used in their preparation. Even in processed food, it is also verified that the foods of vegetable origin presented lower values than animal origin, as can be seen in Table 2. Concerning this last group two different groups, meat, and fish, should be separately evaluated. The meat presented lower values, and in some cases, it was not even possible to quantify the iodine levels (turkey and pork) or in chicken was close of the quantification limit (2.4 μg/100 g), as it was previously reported (Delgado et al., 2018). The exception in meat was minced beef, which already had a higher iodine content, which can be explained by this type of food probably contained ingredients as binders, e.g., eggs that have significant amount of iodine (Becker et al., 2011; Haldimann et al., 2005). On the other hand, the two types of fish analysed were the foods with highest iodine contents, since in the sea iodine's content is significant and relevant for the metabolism of sea living organisms (Fuge and Johnson, 2015; Rohner et al., 2014; Saiz-Lopez et al., 2012). As would be expected, the iodine content is higher in foods that have been cooked with iodized salt than those that have been cooked with traditional salt. Typically, foods cooked without iodized salt, with the exception of foods naturally rich in iodine, presents iodine content below LoQ, in contrast, foods cooked with iodized salt usually present quantifiable contents, in the range between 7.6 μg/100 g (cod) and 29 μg/100 g (rice); a more significant value for the last one it is a consequence of its capacity to incorporate high contents of water (and consequently chemical species dissolved) during the cooking, this fact is also described in the literature (Meinhardt et al., 2019).

It should be noted that foods from animal origin, as milk and its derivatives, yogurt, and cheese, are the main natural contributors to the intake of iodine (Rohner et al., 2014); this is expected since milk is the first food of all mammals, indicating the significant high content of iodine is important for the initial development of the new-borns, and consequently milk derivatives with high protein content maintain significant levels of iodine in their composition (Ellsworth et al., 2020).

Based on these results and the diversity of combinations to daily food consumption it is possible to analyse the different scenarios abovementioned as strategy to identify appropriate intakes of iodine.

Bearing in mind that the European Food Safety Authority (EFSA) indicates that for iodine the Adequate Intake (AI) is 90 μg/day and the Tolerable Upper Intake Level (UL) is 300 μg/day, we carried out a risk-benefit approach, to anticipate the potential impact on health (European Food Safety Authority, 2006, 2014). The estimated iodine levels for each hypothesis of a hypothetical day were grouped into three categories: the first corresponds to values lower than the AI; another that relates to values between AI and UL; and finally, a category corresponding to values above the UL. The results summarized in the Table 5, show in scenario 1, there is 11 % of possibilities that children will not be able to supply the recommended values for daily iodine intake. In scenario 3, there is only a 1 % chance of the maximum tolerable value for iodine intake is exceeded. In scenario 1, the five hundred and seventy-six hypotheses that present a sum of iodine content lesser than 90 μg/day correspond to the hypotheses that do not include any main meal (lunch and dinner) with minced beef or fish. In scenario 3, the forty hypotheses that exceed the value of the tolerable upper intake level for iodine sometimes correspond to the consumption of fish in the two main meals.

Table 5
Number of hypotheses that are within the stipulated ranges of the Adequate Intake (AI) and the Tolerable Upper Intake Level (UL).

	Scenario 1	Scenario 2	Scenario 3
$<$ AI	576 (11 %)	0	0
$\geq$ AI $<$ UL	4608 (89 %)	5184 (100 %)	5144 (99 %)
$\geq$ UL	0	0	40 (1 %)

AI – 90 μg/day; UL – 300 μg/day

It should be noted that foods with low contents of water before cooked and with high capacity to incorporate water can be considered as high contributors for iodine intake if it is added iodized salt in their preparation (Ohlhorst et al., 2012).

Taking into account that Portugal is mentioned as a country with deficiency in iodine intake it is necessary to implement public policies to surpass this problem (Costa Leite et al., 2017; Limbert et al., 2010, 2012; Zimmermann and Andersson, 2011). The present study suggests that for a school-aged children with a balanced and unrestricted diet, at least one meal prepared with iodized salt is necessary to reach the recommended daily iodine intake. Therefore, the use of iodized salt in school canteens is a good way to solve the iodine deficiency in this age group. However, it should be highlighted that not all the meals are taken in schools, neither whole of children have one meal at canteen, and in Azores and Madeira the deficiencies are more significant than in mainland. A previous study showed that, iodized salt consumed in Portugal has a higher iodine content when compared to unfortified salt (Lobato et al., 2019). Furthermore, it is known that all the iodine in the iodized salt is present in its inorganic form and is therefore practically completely absorbed (90 %) (Hurrell, 1997).

Based on all these considerations, a biomonitoring program of iodine content in urine could be a way to complement the surveillance of dietary iodine content so that residual iodine deficiencies or to avoid and excess of this trace element which is also problematic (Costa Leite et al., 2017).

It is also necessary to consider other health conditions that could affect children and could affect the iodine levels, as lactose intolerance, allergies to milk protein, seafood, or eggs, or others with specific diet restrictions (as vegetarian) (Eveleigh et al., 2020). It could be referred, as an example, in the former group if milk and its derivatives are not consumed, shellfish or eggs leads to a loss of very important sources of iodine, while the last group based on a strict vegetarian diet, it has low content of iodine. Several studies also point out this concern, since the consumption of plant-based beverages to the detriment of the consumption of cow's milk can lead to a decrease in iodine intake and a consequent increase in diseases associated with iodine deficiency (Eveleigh et al., 2020; Lazarus, 2021; Melse-Boonstra, 2020). In these groups the use of iodized salt in the preparation of their meals is even a relevant issue to avoid disorders.

4. Conclusions

In our study, we used foods selected from a consumption survey analyzed with a suitable analytical method to determine iodine content. This high-quality data with different iodine contents was successfully applied to several scenarios to estimate the appropriate iodine intake of children using Portuguese data. These results can be helpful for those who want to evaluate the iodine intake to reach the nutritional adequacy of a target population.

Author statement

ID contributed significantly to the conception of the paper, its design, data collection, data interpretation, and analysis. MV and SG contributed significantly to the analysis. RA, ICo, JS and ICa contributed significantly to the interpretation of data and analysis, participated in the writing and critically revised the paper. All authors contributed to the article and approved the submitted version.

Conflict of interest

The authors don't have any competing interests to declare.

Data Availability

Data will be made available on request.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.jfca.2022.105061.

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