J. Dairy Sci. 107:10231–10243
https://doi.org/10.3168/jds.2024-25030


# Low public awareness opens up new opportunities for highlighting milk as an iodine dietary source

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## ABSTRACT

This international survey provides insights into public awareness of the importance of iodine as an essential trace mineral in human health along with knowledge of iodine dietary sources. The online questionnaire included sociodemographic aspects and dietary iodine consumer awareness on 7-point Likert-type questions. A total of 4,704 questionnaires from 16 countries were considered. Answers were analyzed through a multiple regression linear model including country, gender, age, education level, and employment status as fixed effects. Respondents were moderately aware of the importance of fish (4.86) and seafood (4.90) as dietary iodine sources, but less aware of milk as a primary iodine source (3.32). Respondent awareness varied considerably across countries. Age, education level, and employment status only modified their perception when asked about fish and seafood as a source of iodine, with elderly respondents, those highly educated and of working age being more aware of their relevance as dietary iodine sources. Respondent knowledge did not vary by age, education level, employment status, or gender when asked about cereals, vegetables and fruits, meat, and milk as iodine-rich food sources. Consequently, labeling milk and dairy products as an iodine-rich food source should be considered. Public authorities can consider the results from this survey in promotional campaigns to improve the awareness of different iodine sources and their beneficial effect on health.

**Key words:** consumer, health, knowledge, preferences

## INTRODUCTION

Globally, a large number of people suffer from iodine deficiency, which according to the World Health Organization (**WHO**) is considered the most common cause of preventable brain damage (WHO, 2007). Iodine, an essential trace mineral, is a rate-limiting element for synthesizing thyroid hormones, which are fundamental for adequate brain development and growth (Velasco et al., 2018). Substantial iodine deficiency during fetal growth

Received April 10, 2024.
Accepted August 11, 2024.
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The list of standard abbreviations for JDS is available at adsa.org/jds-abbreviations-24. Nonstandard abbreviations are available in the Notes.

and early infancy can lead to profound consequences on intellectual abilities (formerly known as "cretinism"), miscarriages, and infant mortality (WHO, 2007). In contrast, severe iodine deficiency during adult life can be associated with greater hypothyroidism and goiter incidence or enlargement of the thyroid gland (Laurberg et al., 2010). Mild-to-moderate iodine deficiency during pregnancy has been associated with poorer child cognitive development and educational achievements (i.e., learning disabilities and poorer verbal intelligence quotient scores; Levie et al., 2019), with a 10- to 15-point reduction in the intelligence quotient in childhood (Engle et al., 2007; Zimmermann, 2009).

In 1991, the WHO set forth specific guidelines and recommendations to address iodine deficiency disorders, including universal salt iodization, iodine supplementation for vulnerable groups, and health education (WHO, 2007). Soon after, in 1993, the United Nations Children's Fund recommended universal salt iodization as the primary strategy to ensure that all individuals, particularly pregnant women and young children, have access to iodized salt to prevent iodine deficiency and iodine deficiency disorders. However, considerable variability still exists among countries regarding iodine intake and iodine prophylaxis (Bath et al., 2022). Iodine salt policies are mandatory in 126 countries (e.g., Mexico, Brazil, Colombia, Ecuador, Italy, Greece, New Zealand, India, Armenia), but it is voluntary in 21 countries (e.g., Spain, France, Austria, Switzerland, United States; GFDE, 2024). Ironically, based on the most recent recommendations from the WHO, many countries are currently focused on salt-reduction policies to mitigate hypertension and cardiovascular diseases (WHO, 2020), which may affect the efficacy of iodine prophylaxis policies based on universal salt iodization. Consequently, the main sources of salt and iodized salt in Western countries are processed foods (Andersson et al., 2020) such as bread (Haldimann et al., 2005) and ready-made food (Brown et al., 2009). The legislation on iodized salt and its use in processed food varies widely across countries. Therefore, food producers often use noniodized salt in food processing to not limit their import-export market (Andersson et al., 2020).

In this context, animal-origin foods, with particular regard to dairy foods, represent an important dietary source of iodine. Indeed, milk and other dairy products are among the primary natural sources of iodine (Haldimann et al., 2005; Kayes et al., 2022), providing more than half of iodine intake in children in Norway (56%) and the United Kingdom (51%) and contributing at least a third in adults in Finland (37%), Ireland (53%), Norway (36%), and the United Kingdom (34%; Bath et al., 2022). The available iodine in milk and other dairy products can be attributed to several farming practices, especially the practice of iodine supplementation in cattle feed (Vila et al., 2020; Niero et al., 2023). However, the contribution of dairy products to the total iodine intake is mainly overlooked by the public (Kayes et al., 2022), and changes in milk and dairy products consumption habits in the progression from childhood to adulthood could reduce dietary iodine intake (Vila et al., 2020). Despite fish being a reliable source of dietary iodine, given that seawater is naturally abundant in this essential mineral, its contribution to human intake is limited to those countries with a strong fish-related food tradition (i.e., Iceland, Norway, and Mediterranean countries) and especially for adults (Vila et al., 2020; Bath et al., 2022). In children, fish represents between 2% (the Netherlands) and 18% (Norway) of iodine intake whereas, in adults, it represents between 7% (Denmark) and 47% (Iceland; Bath et al., 2022). The generally low iodine content of soils, especially those far from the coast, contributes to crops, fruits, and vegetables being characterized by a low iodine concentration (Dijck-Brouwer et al., 2022). Indeed, vegans and vegetarians are at risk of low iodine intake, even if they consume iodine-fortified plant-based products, which may be insufficient to fill the gap in iodine intake (Alzahrani et al., 2023). An exception is represented by the high iodine content of seaweeds, commonly known as sea vegetables, which contribute to the adequate (and sometimes excessive) iodine intake documented in Japan, where it is widely consumed (Fuse et al., 2022). Moreover, the group of cereals for those countries that have implemented the use of iodized salt in bread such as Belgium and Netherlands increases the contribution of this food group to iodine intake by up to 57% in children and 53% in adults (Bath et al., 2022). Due to their low iodine content, meat and eggs play a secondary role in the daily iodine intake (USDA, 2023). In most countries, iodine intake contribution from eggs is <4%, except for Spain which could reach up to 19% (Bath et al., 2022). On the other hand, iodine intake contribution from meat usually is <5% (Bath et al., 2022).

It would be helpful to have an overview of the population's awareness concerning the importance of iodine intake on health status and its main dietary sources, especially milk. To date, these types of surveys have been conducted only on a national basis or in specific subgroups such as healthcare professionals or childbearing-aged women (Combet et al., 2015; McMullan et al., 2019; Kayes et al., 2022). Therefore, through an international survey, the present study aimed to evaluate respondent awareness across different countries and sociodemographic backgrounds of the importance of iodine in achieving optimal human health status as well as the dietary sources of iodine.

## MATERIALS AND METHODS

### Ethical Statement

Survey participation was voluntary, completely anonymous, and in agreement with the Declaration of Helsinki version 2013 for research involving human subjects from the World Medical Association (WMA, 2023). Data were processed under the General Data Protection Regulation 2016/679 (GDPR) and the Data Protection Act 2018. The study was explained to consumers in the online questionnaire. All participants acknowledged an informed consent statement to participate in the study and were able to withdraw from the survey at any time and without giving a reason.

### Survey Design

The questionnaire entitled "The importance of milk as a source of nutrients: Consumer's survey" consisted of 13 mandatory questions divided into 3 sections designed to gauge opinions and beliefs about dietary iodine on human health status and its dietary sources. The first section (A) included 5 questions capturing sociodemographic information ($Q_{A1}$, $Q_{A2}$, $Q_{A3}$, $Q_{A4}$, and $Q_{A5}$); the second section (B) comprised 7 questions with answers expressed on a 7-point Likert-type item (where 1 means "not at all" and 7 means "very much") or as "I do not know," concerning respondent knowledge about the influence of dietary iodine on health status ($Q_{B1}$) along with the dietary sources of iodine ($Q_{B2}$, $Q_{B3}$, $Q_{B4}$, $Q_{B5}$, $Q_{B6}$, and $Q_{B7}$). The third section (C) included the question ($Q_{C1}$) "How much do you associate calcium with milk?" with the answer expressed on a 7-point Likert-type item (where 1 means "not at all" and 7 means "very much") or as "I do not know," aimed to assess the consistency and the attentiveness of the respondents. The association between calcium and milk ($Q_{C1}$) has been a prominent theme in many milk advertisements in the past, where the role of calcium was frequently highlighted in building and maintaining strong bones and overall well-being. The questionnaire sections, questions, and related answers are shown in Table 1.

The development of the questionnaire followed the workflow described by Manuelian et al. (2023). The first version of the questionnaire was drafted in English by 2 researchers of different nationalities, based on recommendations provided by Dillman (2000). This first version of the questionnaire was then reviewed by 6 researchers of different nationalities and edited based on suggested amendments (second version). Pilot testing of the questionnaire was then conducted with 6 respondents from English-speaking countries to assess question clarity, answer accuracy, and general intelligibility. Once more, the

**Table 1.** Questions and choices included in the survey

| Question | Choice |
|---|---|
| Section A: Sociodemographic information | |
| $Q_{A1}$: In which country do you live? | Close country list |
| $Q_{A2}$: Gender | Male; female; other |
| $Q_{A3}$: Birthdate | Free answer |
| $Q_{A4}$: What is the highest level of education you have completed? | Primary education; secondary education; Bachelor degree; Master degree; Doctorate degree |
| $Q_{A5}$: What is your employment status? | Employed; unemployed; retired; student |
| Section B: Knowledge and awareness | |
| $Q_{B1}$: Do you think that dietary iodine may have an influence on health status? | 1 to 7 Likert-type item (where 1 means "not at all" and 7 means "very much") or "I do not know" |
| $Q_{B2}$: How much do you associate iodine with milk? | 1 to 7 Likert-type item (where 1 means "not at all" and 7 means "very much") or "I do not know" |
| $Q_{B3}$: How much do you associate iodine with fish? | 1 to 7 Likert-type item (where 1 means "not at all" and 7 means "very much") or "I do not know" |
| $Q_{B4}$: How much do you associate iodine with seafood? | 1 to 7 Likert-type item (where 1 means "not at all" and 7 means "very much") or "I do not know" |
| $Q_{B5}$: How much do you associate iodine with meat? | 1 to 7 Likert-type item (where 1 means "not at all" and 7 means "very much") or "I do not know" |
| $Q_{B6}$: How much do you associate iodine with cereals? | 1 to 7 Likert-type item (where 1 means "not at all" and 7 means "very much") or "I do not know" |
| $Q_{B7}$: How much do you associate iodine with vegetables and fruits? | 1 to 7 Likert-type item (where 1 means "not at all" and 7 means "very much") or "I do not know" |
| Section C: Consistency question | |
| $Q_{C1}$: How much do you associate calcium with milk? | 1 to 7 Likert-type item (where 1 means "not at all" and 7 means "very much") or "I do not know" |

questionnaire was edited based on feedback (third version) and was then translated into 13 additional languages (i.e., Arabic, Armenian, French, German, Greek, Hindi, Italian, Japanese, Nepalese, Portuguese, Russian, Spanish, and Tamil) by native speaker researchers following Brislin method (Dufour et al., 2010). All 14 questionnaire versions were implemented in the Google Forms platform and shareable via web or social media platforms through 14 specific web links generated by the system.

## Survey Dissemination and Data Editing

The questionnaire was available from March to September 2022 and distributed through email lists, institutional websites, social platforms (i.e., Facebook, Instagram, and WhatsApp), and personal contacts. Paper leaflets and posters with a brief description of the project and a QR code redirecting to the questionnaire were manually delivered or hung on public notice boards. A token was not given to promote participation. The population of interest included adults residing worldwide, and the ideal sample size goal per country was calculated based on a 95% confidence level and a 5% margin error as:

$$\frac{(Z\,score)^2 \times SD \times (1 - SD)}{Margin\,of\,error^2}.$$

A total of 4,958 questionnaires from 32 countries were recorded. Records associated with underage and obviously wrong ages (n = 63), as well as suspected duplicate records (n = 37) based on sociodemographic questions (i.e., birthdate, country, gender, and the highest educational level) were deleted. As a result, the raw original data set included 4,858 records obtained from 32 countries: Algeria (**DZ**, n = 3), Armenia (**AM**, n = 320), Australia (**AU**, n = 4), Austria (**AT**, n = 641), Belgium (**BE**, n = 1), Brazil (**BR**, n = 408), Canada (**CA**, n = 3), China (**CN**, n = 1), Colombia (**CO**, n = 406), Ecuador (**EC**, n = 192), Egypt (**EG**, n = 17), Estonia (**EE**, n = 1), France (**FR**, n = 286), Greece (**GR**, n = 490), India (**IN**, n = 132), Ireland (**IE**, n = 65), Italy (**IT**, n = 502), Japan (**JP**, n = 76), Mexico (**MX**, n = 402), Morocco (**MA**, n = 14), Nepal (**NP**, n = 16), Netherlands (**NL**, n = 2), New Zealand (**NZ**, n = 67), Pakistan (**PK**, n = 1), Portugal (**PT**, n = 7), Saudi Arabia (**SA**, n = 5), Slovakia (**SK**, n = 1), Spain (**ES**, n = 416), Switzerland (**CH**, n = 127), Tunisia (**TN**, n = 13), United Kingdom (**GB**, n = 19), United States (**US**, n = 174), and other unspecified countries (n = 46). The analysis did not consider countries with less than 60 respondents (i.e., DZ, AU, BE, CA, CN, EG, EE, MA, NP, NL, PK, PT, SA, SK, TN, and GB) and unspecified territories. Therefore, the final edited dataset consisted of 4,704 records from 16 countries (Table 2).

**Table 2.** Profile of the respondents that participated in the study expressed as relative frequency (%)

| Sociodemographic data | Area[1] | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | S-EU | | | NW-EU | | | | N-AM: | L-AM | | | | AS | | | OC: | Total: |
| | IT 502[2] | GR 490 | ES 416 | AT 641 | CH 127 | FR 286 | IE 65 | US 174 | BR 408 | CO 406 | EC 192 | MX 402 | IN 132 | JP 76 | AM 320 | NZ 67 | 16; 4,704 |
| Gender | | | | | | | | | | | | | | | | | |
| Female | 58.8 | 69.8 | 68.8 | 57.7 | 52.0 | 70.6 | 46.2 | 72.4 | 69.6 | 54.7 | 63.0 | 61.2 | 50.0 | 73.7 | 77.2 | 59.7 | 63.8 |
| Male | 40.0 | 27.6 | 30.5 | 39.3 | 45.7 | 27.6 | 53.9 | 25.3 | 30.2 | 44.6 | 35.4 | 37.1 | 49.24 | 25.0 | 21.56 | 40.0 | 34.7 |
| Other | 1.20 | 2.65 | 0.72 | 2.96 | 2.36 | 1.75 | — | 2.30 | 0.25 | 0.74 | 1.56 | 1.74 | 0.76 | 1.32 | 1.25 | — | 1.55 |
| Age class | | | | | | | | | | | | | | | | | |
| Young | 68.3 | 83.1 | 27.9 | 45.7 | 32.3 | 64.0 | 64.6 | 33.9 | 50.3 | 75.3 | 80.2 | 64.4 | 62.12 | 44.7 | 55.63 | 50.8 | 58.2 |
| Adult | 28.9 | 16.9 | 66.1 | 52.3 | 66.1 | 35.7 | 35.4 | 60.3 | 45.8 | 22.4 | 19.3 | 32.8 | 37.12 | 52.6 | 42.50 | 41.8 | 39.4 |
| Senior | 2.79 | — | 6.01 | 2.03 | 1.57 | 0.35 | — | 5.75 | 3.92 | 2.22 | 0.52 | 2.7 | 0.76 | 2.63 | 1.88 | 7.5 | 2.5 |
| Education | | | | | | | | | | | | | | | | | |
| Doctorate | 5.78 | 6.73 | 20.4 | 30.9 | 47.2 | 12.9 | 44.6 | 22.4 | 17.2 | 4.19 | 2.60 | 5.47 | 36.36 | 9.21 | 14.38 | 43.3 | 16.0 |
| University | 45.4 | 32.9 | 57.0 | 47.4 | 41.7 | 67.1 | 55.4 | 63.8 | 26.0 | 37.4 | 35.9 | 35.3 | 57.58 | 69.7 | 61.88 | 53.7 | 45.8 |
| Nonacademic | 48.8 | 60.4 | 22.6 | 21.7 | 11.0 | 19.9 | — | 13.8 | 56.9 | 58.4 | 61.5 | 59.2 | 6.06 | 21.1 | 23.75 | 2.99 | 38.2 |
| Employment | | | | | | | | | | | | | | | | | |
| Employed | 57.2 | 46.1 | 77.6 | 81.3 | 92.9 | 49.0 | 67.7 | 89.7 | 60.3 | 34.5 | 22.9 | 46.3 | 50.76 | 76.3 | 79.06 | 59.7 | 60.6 |
| Unemployed | 3.98 | 39.1 | 3.13 | 1.69 | 0.79 | — | — | 0.57 | 7.35 | 8.62 | 10.4 | 8.96 | 8.33 | 1.32 | 5.00 | 1.49 | 8.2 |
| Retired | 4.98 | — | 9.62 | 2.18 | 2.36 | 1.40 | — | 4.02 | 5.64 | 2.71 | — | 3.23 | 1.52 | — | 1.56 | 2.99 | 3.2 |
| Student | 33.9 | 14.7 | 9.62 | 15.4 | 3.94 | 49.7 | 32.3 | 5.75 | 26.7 | 54.2 | 66.7 | 41.5 | 39.39 | 22.4 | 14.38 | 35.8 | 28.1 |

[1]S-EU = Southern Europe; NW-EU = Northern and Western Europe; N-AM = Northern America; L-AM = Latin America; AS = Asia; OC = Oceania.

[2]Country and number of respondents. IT = Italy; GR = Greece; ES = Spain; AT = Austria; CH = Switzerland; FR = France; IE = Ireland; US = United States; BR = Brazil; CO = Colombia; EC = Ecuador; MX = Mexico; IN = India; JP = Japan; AM = Armenia; NZ = New Zealand.

### Statistical Analysis

Sources of variation for answers to the questions on the 7-point Likert-type item were investigated through a multiple regression fixed effects model implemented in the MIXED procedure of SAS v. 9.4 (SAS Institute Inc., Cary, NC) according to:

$$y_{ijklmno} = \mu + \text{Country}_i + \text{Gender}_j + \text{Age}_k + \text{Education}_l + \text{Employment}_m + \text{Respondent}_n + \text{e}_{ijklmno},$$

where $y_{ijklmno}$ is the dependent variable; $\mu$ is the overall intercept of the model; $\text{Country}_i$ is the fixed effect of the $i$th residence country of the respondents (16 classes: IT, GR, ES, AT, CH, FR, IE, US, BR, CO, EC, MX, IN, JP, AM, NZ); $\text{Gender}_j$ is the fixed effect of the $j$th gender class of the respondents (3 classes: female, male, other); $\text{Age}_k$ is the fixed effect of the $k$th age class of the respondents (3 categories: young, ≤35 years old; adult, between 36 and 64 years old; senior, ≥65 years old); $\text{Education}_l$ is the fixed effect of the $l$th education class of the respondents (3 categories: doctorate; university; nonuniversity, having completed primary or secondary education); $\text{Employment}_m$ is the fixed effect of the $m$th employment status of the respondents (4 categories: employed; unemployed; retired; student); $\text{Respondent}_n$ is the random effect of the $n$th respondent ($n$ = 1 to 4,704), $\sim \text{N}\left(0, \sigma^2_{\text{Respondent}}\right)$; and $\text{e}_{ijklmno}$ is the random residual, $\sim \text{N}\left(0, \sigma^2_{\text{e}}\right)$, where $\sigma^2_e$ is the residual variance. Moreover, countries were grouped through the LSMESTIMATE statement of PROC MIXED to assess geographical area patterns based on the United Nations (UN) geoscheme regions: Southern Europe (including IT, GR, and ES); Northern and Western Europe (including AT, CH, FR, and IE); Northern America (including the US); Latin America (including BR, CO, EC, and MX); Asia (including IN, JP, and AM); and Oceania (including NZ). Differences between LSM were tested using the Bonferroni post hoc multiple comparison tests ($P < 0.05$).

## RESULTS

### Respondent Characteristics

Demographic characteristics (i.e., education, employment status, age, and gender) of the 4,704 participants within and across the 16 countries involved in the study are shown in Table 2. Most of the respondents were female (63.8%), followed by male respondents (34.7%). Across the study population, most respondents were young (58.2%). However, this pattern was not constant across countries, where for 31% of the countries, the majority of the respondents were adults. Greece registered the greatest percentage of young respondents (83.1%), and CH and ES had the greatest percentage of adult respondents (66.1%). The greatest percentage of senior respondents was observed for NZ (7.5%).

On average, 45.8% and 16.0% of the respondents had a university degree or a doctorate, respectively, as their highest education level. However, within a country, the reported education level varied considerably. Approximately 60% of the respondents from GR, EC, MX, and CO had nonacademic education, and more than 97% of NZ respondents had an academic degree. Regarding doctorate education, the frequency ranged from 47.2% (CH) to 2.6% (EC) of the respondents.

The 60.6% and 28.1% of the respondents were employed or students, respectively, but these frequencies varied by country. The greatest percentage of people who categorized themselves as employed lived in CH (92.9%), the US (89.7%), and AT (81.3%). In contrast, GR registered the greatest percentage of unemployed respondents (39.1%). The highest percentage of students among the respondents per country was registered in EC (66.7%), CO (54.2%), and FR (49.65%).

### Descriptive Statistics

The overall scores for questions $Q_{B1}$ to $Q_{B7}$ are shown in Table 3. The lowest proportion of respondents who

**Table 3.** Descriptive statistics[1] for questions with answers on a 1 to 7 Likert-type item (where 1 means "not at all" and 7 means "very much")

| Question | N | Mean | SD | 5th pct | 95th pct | Skew | Kurt | %Nk |
|---|---|---|---|---|---|---|---|---|
| $Q_{B1}$: Do you think that dietary iodine may have an influence on health status? | 3,882 | 5.23 | 1.55 | 2.00 | 7.00 | −0.82 | 0.01 | 17.5 |
| $Q_{B2}$: How much do you associate iodine with milk and dairy products? | 3,605 | 3.32 | 1.78 | 1.00 | 7.00 | 0.32 | −0.83 | 23.4 |
| $Q_{B3}$: How much do you associate iodine with fish? | 3,897 | 4.86 | 1.86 | 1.00 | 7.00 | −0.52 | −0.83 | 17.2 |
| $Q_{B4}$: How much do you associate iodine with seafood? | 3,847 | 4.90 | 1.91 | 1.00 | 7.00 | −0.55 | −0.86 | 18.2 |
| $Q_{B5}$: How much do you associate iodine with meat? | 3,628 | 3.52 | 1.67 | 1.00 | 7.00 | 0.14 | −0.72 | 22.9 |
| $Q_{B6}$: How much do you associate iodine with cereals? | 3,566 | 3.11 | 1.65 | 1.00 | 6.00 | 0.41 | −0.59 | 24.2 |
| $Q_{B7}$: How much do you associate iodine with vegetables and fruits? | 3,651 | 3.44 | 1.80 | 1.00 | 7.00 | 0.31 | −0.84 | 22.4 |

[1]N = total number of respondents; 5th pct = 5th percentile; 95th pct = 95th percentile; Skew = skewness; Kurt = kurtosis; %; Nk = percentage of respondents who selected "I do not know."

answered "I do not know" was registered when asked about the influence of dietary iodine on health status ($Q_{B1}$, 17.5%) and the relevance of fish ($Q_{B3}$, 17.2%) and seafood ($Q_{B4}$, 18.2%) as iodine dietary sources (Table 3). For these 3 questions, respondents indicated moderately high average scores ($Q_{B1}$, 5.2; $Q_{B3}$, 4.9; $Q_{B4}$, 4.9; on the 7-point scale). When asked about milk and dairy products ($Q_{B2}$), meat ($Q_{B5}$), cereals ($Q_{B6}$), and vegetables and fruits ($Q_{B7}$) as iodine sources, between 22.9% and 24.2% of the respondents did not have an opinion (i.e., they answered "I don't know"). The average score assigned to the former food groups was always below 3.6 points. In particular, milk recorded the second lowest score ($Q_{B2}$, 3.3) after cereals ($Q_{B6}$, 3.1). Based on $Q_{C1}$ ("How much do you associate calcium with milk?"), we can assume that respondents were attentive and consistent when answering the questionnaire, with an interquartile range of 5.0 to7.0 and an average score of 5.9. Only 5% of the respondents selected "Not at all" (1.9%) or "I do not know" (3.2%) for this question.

### Iodine Awareness Based on Geographical Area and Country

Across the 6 different geographical areas shown in Figure 1, respondents from Oceania were highly aware of the influence of the role of dietary iodine on health status ($Q_{B1}$, 5.9, $P < 0.05$). At the same time, Latin America had the lowest score ($Q_{B1}$, 4.9, $P < 0.05$). The remaining geographical areas agreed (above 5.00 on the 7-point scale) that dietary iodine influences health status. The awareness of milk as an iodine-rich food was rather low ($Q_{B2}$, 3.32; Table 3), with the lowest score in Northern and Western Europe (3.0, $P < 0.05$). There was a high awareness of the relevance of fish ($Q_{B3}$) and seafood ($Q_{B4}$) as iodine dietary sources across all the geographical areas investigated (between 5.4 and 5.5), particularly in Europe. The perception of meat as a dietary iodine source ($Q_{B5}$) had the greatest score in North America (4.7, $P < 0.05$); this differed from the other countries, which generally had a more neutral opinion (between 3.5

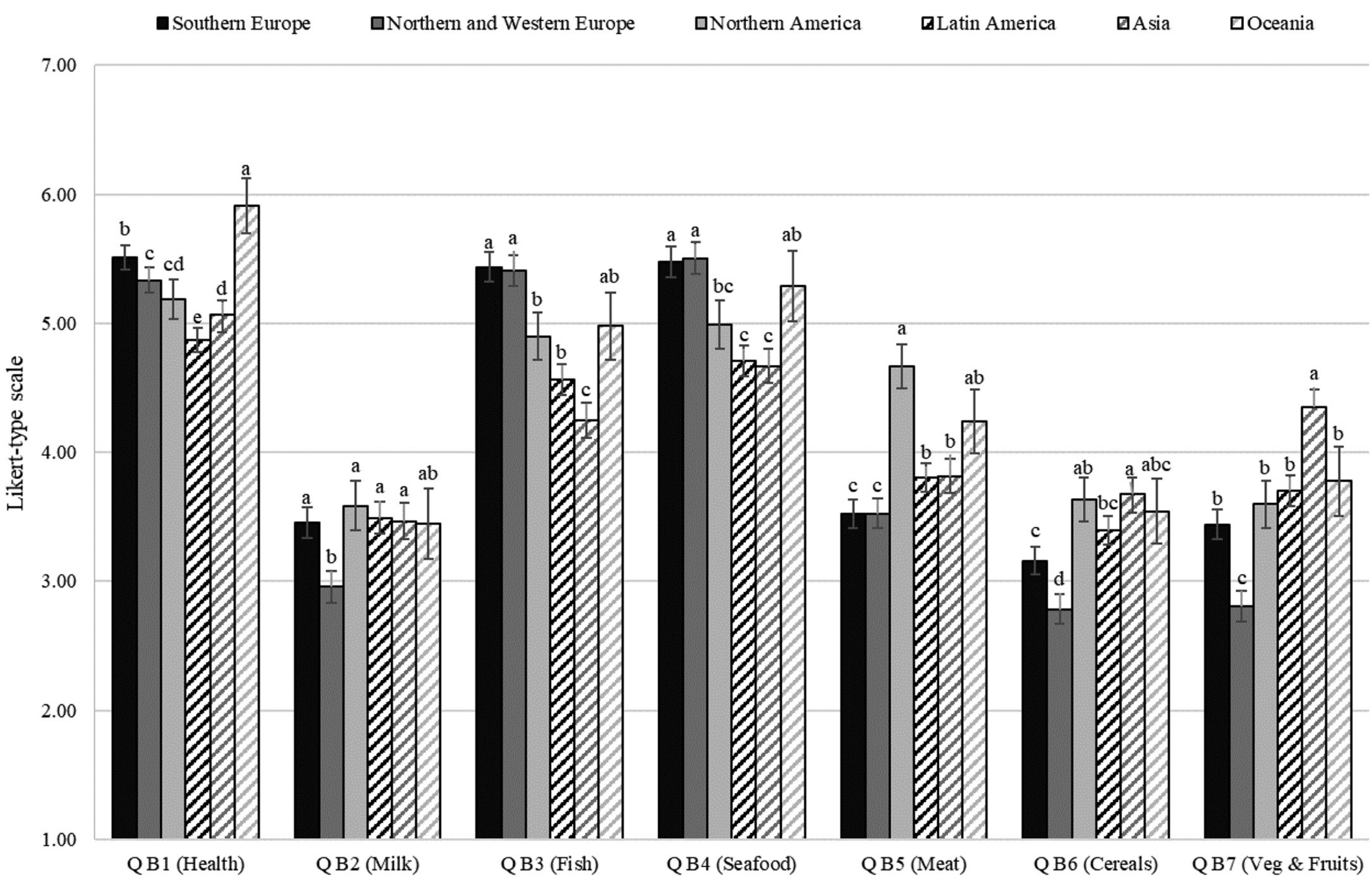


**Figure 1.** Least squares means (with SE) for geographical area included in the study (Southern Europe, n = 1,408; Northern and Western Europe, n = 1,119; Northern America, n = 174; Latin America, n = 1,408; Asia, n = 528; Oceania, n = 67). See Table 2 for the complete questions. Different lowercase letters (a–e) within a question indicate $P < 0.05$ based on Bonferroni post hoc test. Veg = vegetables.

and 4.2). In the same way, the perception of vegetables and fruits as dietary iodine sources ($Q_{B7}$) was higher in Asia (4.4, $P < 0.05$) than in the other regions, with the lowest score observed in Northern and Western Europe (2.8, $P < 0.05$). In addition, the perception of cereals as dietary iodine sources ($Q_{B6}$) was, in general, closer to neutrality, with Asia (3.7) and Northern and Western Europe (2.8) having the greatest and the lowest scores, respectively ($P < 0.05$).

Results across the 16 countries participating in the study are shown in Table 4. Respondents from NZ (5.9), GR (5.6), and IT (5.6) were the most aware of the influence of dietary iodine on health status ($Q_{B1}$, $P < 0.05$). In contrast, respondents from CO (4.7), MX (4.6), EC (4.5), and JP (4.5) recorded the lowest scores ($P < 0.05$). Respondents exhibited a notably low awareness of milk products as a source of iodine ($Q_{B2}$), with the highest scores ($P < 0.05$) recorded in JP (3.9), MX (3.8), IT (3.7), CO (3.6), and US (3.6) and the lowest scores ($P < 0.05$) observed in AT (2.9) and FR (2.9). Nevertheless, French respondents demonstrated the greatest awareness of fish ($Q_{B3}$, 6.0) and seafood ($Q_{B4}$, 6.4) as dietary iodine sources. Respondents from AM and IN declared a more neutral position regarding fish (AM, 4.2; IN, 4.3) and seafood (AM, 4.8; IN, 4.4). When inquiring about the role of meat as a dietary iodine source ($Q_{B5}$), a more impartial perspective was evident across various countries, with scores ranging from 4.6 for the US to 3.2 for FR ($P < 0.05$). Of the countries involved in the present study, JP registered the greatest scores for cereals ($Q_{B6}$,4.2) and vegetables and fruits ($Q_{B7}$, 5.1) as dietary iodine sources.

## *Iodine Awareness Based on Sociodemographic Characteristics*

Figure 2 summarizes responses according to gender and age class. The score attributed to the impact of dietary iodine on health status ($Q_{B1}$) was influenced by the respondent gender, such that females attributed slightly higher scores than males ($P < 0.05$; Figure 2A). However, all genders scored close to 5.0. On the other hand, gender did not modify respondents' perception of food groups contributing to dietary iodine ($Q_{B2}$ to $Q_{B7}$; $P > 0.05$). The awareness of the respondents about fish ($Q_{B3}$) and seafood ($Q_{B4}$) as dietary iodine sources increased with age ($P < 0.05$; Figure 2B). However, scores related to senior respondents should be interpreted with caution due to the low number of respondents older than 65.

Figure 3 summarizes responses based on education level and employment status. Scores were not associated with education level (Figure 3A) except for 3 questions: the awareness of the importance of iodine in health ($Q_{B1}$), and the awareness of fish ($Q_{B3}$) and seafood ($Q_{B4}$)

**Table 4.** Least squares means for countries included in the study[1]

| Question | Country[2] | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $Q_{B1}$ (Health) | NZ $5.91^{a}$ | GR $5.64^{a}$ | IT $5.64^{a}$ | CH $5.60^{ab}$ | BR $5.42^{ab}$ | IN $5.42^{ab}$ | IE $5.41^{abc}$ | AT $5.35^{abc}$ | US $5.19^{abc}$ | ES $5.18^{abc}$ | FR $5.16^{abc}$ | AM $5.07^{bc}$ | CO $4.65^{c}$ | MX $4.57^{c}$ | EC $4.53^{c}$ | JP $4.49^{c}$ |
| $Q_{B2}$ (Milk and dairy) | JP $3.93^{a}$ | MX $3.80^{a}$ | IT $3.65^{a}$ | CO $3.64^{a}$ | US $3.59^{a}$ | IN $3.55^{ab}$ | EC $3.46^{ab}$ | NZ $3.46^{ab}$ | GR $3.42^{ab}$ | CH $3.39^{ab}$ | AM $3.37^{ab}$ | ES $3.28^{ab}$ | IE $3.26^{ab}$ | BR $3.15^{ab}$ | AT $2.90^{b}$ | FR $2.89^{b}$ |
| $Q_{B3}$ (Fish) | FR $6.00^{a}$ | GR $5.87^{a}$ | CH $5.28^{ab}$ | ES $5.25^{ab}$ | IT $5.18^{ab}$ | IE $5.12^{abc}$ | AT $5.10^{bc}$ | BR $4.95^{bc}$ | NZ $4.94^{bcd}$ | US $4.87^{bcd}$ | EC $4.54^{bcd}$ | JP $4.46^{bcd}$ | MX $4.36^{cd}$ | CO $4.32^{cd}$ | IN $4.27^{cd}$ | AM $4.19^{d}$ |
| $Q_{B4}$ (Seafood) | FR $6.39^{a}$ | GR $6.01^{ab}$ | ES $5.44^{bc}$ | CH $5.36^{bcd}$ | NZ $5.25^{b-e}$ | IE $5.22^{b-e}$ | BR $5.21^{cde}$ | AT $5.03^{cde}$ | IT $4.99^{cde}$ | US $4.97^{cde}$ | AM $4.75^{cde}$ | JP $4.68^{cde}$ | EC $4.60^{de}$ | MX $4.47^{e}$ | CO $4.39^{e}$ | IN $4.36^{e}$ |
| $Q_{B5}$ (Meat) | US $4.64^{a}$ | NZ $4.23^{ab}$ | JP $4.21^{ab}$ | IN $4.09^{ab}$ | MX $4.01^{ab}$ | CO $3.93^{ab}$ | IE $3.74^{abc}$ | EC $3.71^{bc}$ | AT $3.66^{bc}$ | ES $3.64^{bc}$ | AM $3.62^{bc}$ | GR $3.61^{bc}$ | BR $3.44^{bc}$ | CH $3.34^{bc}$ | IT $3.31^{c}$ | FR $3.18^{c}$ |
| $Q_{B6}$ (Cereals) | JP $4.19^{a}$ | IN $4.18^{a}$ | US $3.62^{ab}$ | NZ $3.55^{abc}$ | MX $3.55^{abc}$ | CO $3.53^{abc}$ | EC $3.40^{abc}$ | AM $3.38^{abc}$ | ES $3.26^{abc}$ | IE $3.25^{abcd}$ | GR $3.11^{bcd}$ | IT $3.08^{bcd}$ | BR $3.08^{bcd}$ | AT $2.83^{cd}$ | CH $2.66^{cd}$ | FR $2.60^{d}$ |
| $Q_{B7}$ (Veg[3] and fruits) | JP $5.11^{a}$ | IN $4.59^{ab}$ | AM $4.12^{bc}$ | MX $4.09^{bc}$ | CO $3.92^{bcd}$ | NZ $3.78^{b-e}$ | EC $3.65^{cde}$ | ES $3.59^{cde}$ | US $3.58^{cde}$ | IT $3.36^{de}$ | GR $3.36^{de}$ | IE $3.17^{def}$ | BR $3.13^{ef}$ | AT $2.84^{f}$ | FR $2.72^{f}$ | CH $2.60^{f}$ |

[a–f]Different superscripts within question indicate $P < 0.05$ based on a Bonferroni post hoc test.

[1]See Table 2 for the complete questions.

[2]The LSM (and country associated with the LSM) are listed in rank order (highest score to lowest score) for each question. IT = Italy; GR = Greece; ES = Spain; AT = Austria; CH = Switzerland; FR = France; IE = Ireland; US = United States; BR = Brazil; CO = Colombia; EC = Ecuador; MX = Mexico; IN = India; JP = Japan; AM = Armenia; NZ = New Zealand.

[3]Veg = vegetables.

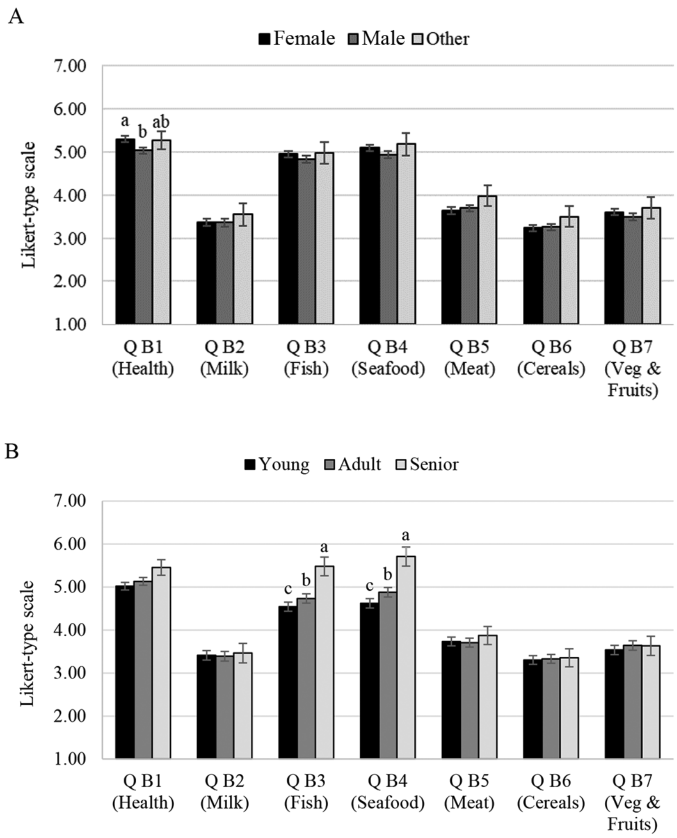


**Figure 2.** Least squares means (with SE) for (A) gender (female, n = 2,999; male, n = 1,632; Other, n = 73) and (B) age class (Young, ≤35 years old, n = 2,736; Adult, 36–65 years old, n = 1,852; Senior, ≥65 years old, n = 116). See Table 2 for the complete questions. Different lowercase letters (a–c) within a question indicate $P < 0.05$ based on Bonferroni post hoc test. Veg = vegetables.

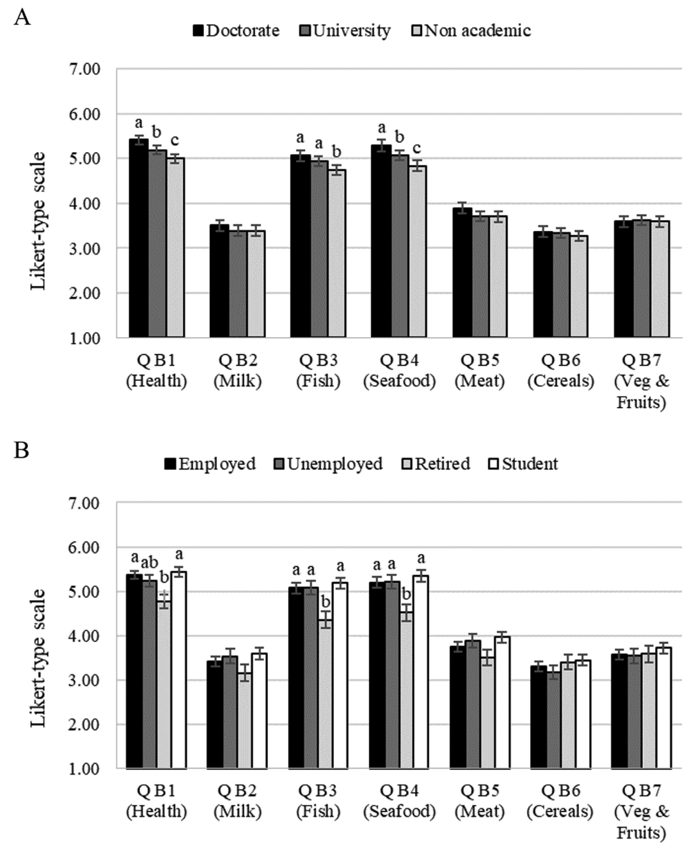


**Figure 3.** Least squares means (with SE) for (A) education level (doctorate, n = 754; university, n = 2,154; nonacademic, n = 1,796) and (B) employment status (employed, n = 2,849; unemployed n = 384; retired, n = 149; student, n = 1,322). See Table 2 for the complete questions. Different lowercase letters (a–c) within a question indicate $P < 0.05$ based on Bonferroni post hoc test. Veg = vegetables.

as dietary iodine sources. For these 3 questions, respondents with doctorate degrees scored higher, followed by respondents with university degrees and respondents without academic degrees ($P < 0.05$). Figure 3B summarizes responses based on employment level. Again, the results did not differ much by employment status, except for respondent awareness of the impact of dietary iodine on health status ($Q_{B1}$) and the contribution of fish ($Q_{B3}$) and seafood ($Q_{B4}$) to dietary iodine. For all 3 questions, retired people had a lesser awareness than in all the other categories ($P < 0.05$).

## DISCUSSION

The present multicountry survey included 16 countries covering America, Europe, Asia, and Oceania. Respondents were mainly young females with a university degree and employed. Respondents were moderately highly aware of the influence of dietary iodine on health status and the importance of fish and seafood as dietary iodine sources. However, they were hesitant when asked about other food groups, as can be inferred from the greater nonresponse rate, and the more neutral score was assigned, in particular, of the role of milk and dairy products as a primary iodine source.

The country where the survey was conducted highly influenced the respondent's perception of the influence of dietary iodine on health status and the importance of the different food groups as dietary iodine sources. Those differences could be related to the country's dietary habits and food group access, such as the Mediterranean diet or access to fish, seafood, and seaweeds. On the other hand, age, education level, and employment status were only significant when asked about fish and seafood as a source of iodine, with elderly respondents, those highly educated, and of working age being more aware of their relevance as dietary iodine sources. Respondent knowledge did not vary by age, education level, employment status, or gender when asked about cereals, vegetables and fruits, meat, and milk as sources of iodine.

### Greater Participation from Young Females with Higher Education

The greater participation from females is comparable to that reported by Vargas-Bello-Pérez et al. (2020), who investigated consumer knowledge and perceptions of milk fat in DK, GB, and the US. Vargas-Bello-Pérez et al. (2020) reported that 73% of the respondents were female, and only 27% were male. The predominance of female respondents in online surveys has already been described in the literature (Smith, 2008; Wu et al., 2022). A potential explanation for the observed gap is the difference between how males and females make decisions and value actions online (Smith, 2008; Wu et al., 2022).

The general greatest participation of young respondents is supported by young people being generally more familiar with and more likely to participate in online surveys than older people (Andrews et al., 2003; Remillard et al., 2014). Younger generations have grown up with technology and the internet, and they are more comfortable using online platforms and have greater familiarity with various digital tools, including survey interfaces.

It is relevant to mention that respondent proportions are biased toward those with higher education, because the questionnaire was mainly distributed through academic channels. Still, a strength of the conducted survey was the proportion of respondents with nonacademic education reached (about 38%; Table 2) because they can bring diverse perspectives and valuable insights (unique viewpoints and real-world experiences) to our research because these respondents received education outside of traditional academic institutions, such as vocational training, technical certifications, or on-the-job training. The access to academic education and doctoral programs can vary between countries and is influenced by educational systems, resources, and policies. Such information is very valuable for understanding the educational background of respondents in different countries.

### Low Awareness of Food Categories Contribution to Iodine Intake

The proportion of respondents without a clear position on the influence of dietary iodine on health status and the relevance of fish and seafood as iodine dietary sources is lower (i.e., proportion of respondents answering "I do not know," 17%–18%) than the findings described by Henjum et al. (2018), who observed that 32.5% of 403 young Norwegian women did not know about the importance of iodine for human health and that 22.3% of the same population did not know about the most important dietary iodine sources. The proportion of respondents in the present study without a clear position is also considerably lower compared with the findings of Jooste et al. (2005), who reported that 60.8% out of 2,164 adult respondents from South Africa did not know which are the iodine dietary sources. Such differences are likely because questions formulated in our study were associated with Likert-type item answers, which may have limited the frequency of respondents answering "I do not know." In contrast, the questions formulated by Jooste et al. (2005) and Henjum et al. (2018) were associated with a multiple-choice answer, which may have inflated the frequency of respondents answering "I do not know."

The high score we registered for fish and seafood as relevant dietary iodine sources agreed with the literature, where indeed fish and seafood are described as iodine-rich foods (Haldimann et al., 2005; Sprague et al., 2021). Moreover, consumer awareness about fish and seafood as healthy nourishment reflects both public beliefs and information campaigns promoted by different stakeholders (e.g., governments, consumer organizations, and health professionals; Carlucci et al., 2015).

The relatively low awareness of the contribution of milk and dairy products as sources of dietary iodine, despite being described as primary dietary sources (van der Reijden et al., 2017; Niero et al., 2020, 2023), suggests that knowledge about iodine is not widespread in the general public. A similar lack of awareness was also reported by other authors (Jooste et al., 2005; Charlton et al., 2010) when considering specific groups of people where milk consumption is especially important, such as pregnant women and mothers of children up to 36 mo old (O'Kane et al., 2016; Bath et al., 2022). Some potential reasons for this lack of knowledge among people could be that information about iodine and nutrition is often limited to scientific publications, making it less accessible and reachable by the general public. This must be added to the fact that public health campaigns and educational initiatives might not effectively reach certain demographic groups or communities, leading to a lack of awareness (Abroms and Maibach, 2008).

### Geographical Area and Country Affected Dietary Iodine Consumers' Awareness

The lower score assigned by JP compared with the other countries on the fact that dietary iodine influences health status could be influenced by their diet. Regarding meeting iodine requirements, the JP population represents an exception, with adequate and sometimes excessive iodine intake, principally due to the diffused consumption of iodine-rich seaweeds (Fuse et al., 2022). This aspect may likely have lowered their perception of iodine as a limiting factor for human health.

Surprisingly, the lowest score assigned by the respondents to milk as an iodine-rich food was observed in Northern and Western Europe (2.96), even though the estimated milk consumption in this region is relatively high (232.05 and 236.17.59 kg/capita per year, respectively) compared with other regions (FAOSTAT, 2024). The scores obtained for this food group might be interpreted as an indication that respondents lack a clear understanding of the contribution of these products to dietary iodine, despite milk and dairy products contributing between 13% and 64% of iodine consumption in nonpregnant adults (Krela-Kaźmierczak et al., 2021), and despite the newly updated Dietary Guidelines for Americans, which has listed iodine among the essential micronutrients (US Department of Agriculture and US Department of Health and Human services, 2020).

For meat as a dietary iodine source, North America attributed a more positive opinion, and the other regions showed a more neutral score, suggesting that food group consumption contributes to building consumer awareness because North America has the greatest estimated meat supply (122.8 kg/capita per year) among all studied regions (between 33.5 kg/capita per year in Asia to 105.4 kg/capita per year in Australia and New Zealand; FAOSTAT, 2024). The fact that the US registered the greatest score is probably related to the great meat consumption in the US (Daniel et al., 2011; FAOSTAT, 2024), which may have inflated respondent opinion on meat as an iodine dietary source (Haldimann et al., 2005).

In the same way, a greater perception of vegetables and fruits as dietary iodine sources in Asia than in the other regions is in line with Asia being the one with the greatest estimated vegetable supply availability (Asia, 187.4 kg/capita per year; between 54.2 and 170.3 kg/capita per year in Southern America and Western Europe, respectively; FAOSTAT, 2024). In addition, Asia also has the greatest cereal supply availability (Asia, 201.6 kg/capita per year; between 109.8 and 144.2 kg/capita per year in Australia and New Zealand and Southern Europe, respectively; FAOSTAT, 2024), which could explain the greatest score for the perception of cereals as dietary iodine sources obtained for Asia. In particular, the position of JP among the other countries regarding these 2 food groups could be explained by the distinctive traits of the Japanese culinary tradition, which may have led to an inflated association between rice (as a cereal) and iodine (Francks, 2007) and to an inflated association between seaweeds (as a vegetable) and iodine (Fuse et al., 2022). Only 3 countries worldwide report seaweed consumption: the Republic of Korea, CN, and JP, with 32.2, 13.4, and 0.9 kg/capita per year, respectively (FAOSTAT, 2024). The hypothesis of the relevance of rice consumption to influence their perception is also supported by the fact that IN ranked in the second position of countries investigated in the present study for the association between iodine and cereals. These 2 countries, IN and JP, were the ones included in the present study with the greatest rice consumption in the year 2018 (IN, 97.8 vs. JP, 81.7 kg/capita per year; FAOSTAT, 2024). Although rice (polished grain) has generally a low concentration of iodine (≤58 ng/g; Fordyce et al., 2000; Tsukada et al., 2008), others reported a considerably greater concentration (333 ng/g; Haldimann et al., 2005), which suggests that their rice samples contain iodine-fortified grains (Cakmak et al., 2020). Despite a few countries indicating a neutral opinion on the role of cereals, vegetables, and fruits in providing dietary iodine, most have a clearer awareness of the low contribution of these food groups to dietary iodine (Haldimann et al., 2005).

### Sociodemographic Characteristics Only Modify Dietary Iodine Awareness for Fish and Seafood

Regarding gender, the lack of association between respondent perception of food group with dietary iodine contrasted with Parmenter et al. (2000), who reported that women, on average, have greater knowledge than men in respect to human nutrition facts and issues, including dietary recommendations, sources of nutrients, healthy food choices, and diet-disease links. The difference in gender awareness between both our results and Parmenter et al. (2000), could be related to the specificity of the questions we proposed compared with Parmenter et al. (2000). Such specificity may have reduced the potential gender differences. Moreover, gender differences could also be diluted due to the progressive rise in the number of people living alone (Bridgwood and Savage, 1993) and therefore being in control of shopping and cooking (Parmenter et al., 2000) independently of their gender. However, in line with the results of Parmenter et al. (2000), we observed that females were more aware of the importance of iodine in health. On the other hand, the increasing awareness of the respondents about fish and seafood as dietary iodine sources with age could be explained due to eating behaviors as fish and seafood consumption, on average, increases with age (Thorsdottir et al., 2012).

The greater awareness observed among respondents with doctorate and academic degrees on the importance of iodine in health and fish and seafood as dietary iodine sources could be attributed to a greater readiness for nutritional facts and easier access to information sources rather than the specific knowledge acquired during university studies. Parmenter et al. (2000) reached comparable conclusions when examining demographic variability in human nutritional knowledge among 1,040 English individuals. Parmenter et al. (2000) specified that a higher education level is associated with a better understanding of written material like newspaper articles and leaflets and that more educated people can better understand the complex information regarding the connections between dietary habits and disease.

### Limitations, Applications, and Perspectives

The current survey provides an overview of respondent awareness about dietary sources of iodine. However, it is essential to note that the population sample in the present study may not entirely reflect the actual demographics of the selected countries. This aspect was expected because it is intrinsically embedded in the methodology of voluntary surveys, which are still considered important tools for gathering data at a population level (Couper and Miller, 2008). For instance, the distribution of the current questionnaire primarily through academic channels might have disproportionately increased the response rate among specific sociodemographic groups (such as young individuals with academic degrees) while potentially overlooking other potential respondents (like seniors with nonacademic education). Nevertheless, the demographics of the respondents in the present study closely resemble those reported by Vargas-Bello-Pérez et al. (2020), who collected data through a web-based questionnaire on consumer knowledge and perception of milk fat, and Diekman and Malcolm (2009) and Saulais et al. (2012), who conducted phone and face-to-face questionnaire interviews to examine consumer knowledge on the quality of dietary fats.

With appropriate caution, the findings of the present study provide a global overview of knowledge regarding the importance of iodine in human health and the dietary iodine content in various food groups. The results of this study could provide valuable insights for the public health sector, especially in identifying strategic areas and methods for promoting targeted educational campaigns, and informative food labels, packaging claims, and infographics to boost iodine awareness and promote appropriate iodine intake through diet. Especially considering the limited respondent knowledge about milk products as key sources of iodine, it would be beneficial to provide precise labeling and packaging claims designating dairy products as iodine-rich food sources. Implementing this relatively straightforward action could yield tangible and immediate benefits for consumers by enhancing iodine awareness and prophylaxis (Cowburn and Stockley, 2005).

## CONCLUSIONS

The current study was based on 4,704 records from respondents who voluntarily participated in an international survey using a self-administered online questionnaire focused on the importance of iodine in human health and dietary iodine sources. Respondents were, on average, aware of iodine's significant role in general health status but were not well informed about dietary iodine sources. Although fish and seafood were correctly identified as good dietary iodine sources, there were generalized misconceptions that milk and dairy products were inadequate and that cereals and meat were good sources in JP and the US, respectively. Increased awareness of iodine content in food categories and its health implications was observed among individuals with higher levels of education. Thus, public authorities should consider additional initiatives to increase general public awareness of actual dietary iodine sources.

## NOTES

This project was funded by the "MEP CASEUS – Strategie per il miglioramento dell'efficienza produttiva e qualitativa del settore lattiero-caseario – CDS000632" (Latteria di Soligo, Farra di Soligo, Italy). CLM is currently a postdoctoral researcher funded with a María Zambrano grant from the Spanish Ministry of Universities (Madrid, Spain; funded by European Union-Next Generation EU; MZ2021-86). The funders played no role in the design of the study, the collection, analysis, and interpretation of data, or the writing of the manuscript. The authors are grateful to Leonard Barnabas (University of Padova, Legnaro, Italy) for the Tamil translation, to Ali El-Hadi (Universitat Autònoma de Barcelona, Bellaterra, Spain), Ahmed Salama (Universitat Autònoma de Barcelona), and Ali Zidi (Hispatec Analytics, Almería, Spain) for the Arabic translation and dissemination in Algeria, Egypt, Morocco, Saudi Arabia, and Tunisia, to Nisha Sharma (University of Padova) for the Nepali translation, to Sajad Majeed Zargar (University of Padova) for the Hindi translation, and Sevada Sahakian (Asociación Cultural Armenia de Barcelona, Barcelona, Spain) for helping in the dissemination in Armenia, and to Sarah C. Bath (University of Surrey, Guildford, UK) for helpful assistance. The data presented in this study are available free of charge for any user at the official data repository CORA RDR (https://doi.org/10.34810/data1779). Survey participation was voluntary, completely anonymous, and in agreement with the Declaration of Helsinki version 2013 for research involving human subjects from the World Medical Association (WMA, 2023). Data were processed under the General Data Protection Regulation 2016/679 (GDPR) and the Data Protection Act 2018. The study was explained to consumers in the online questionnaire. All participants acknowledged an informed consent statement to participate in the study and were able to withdraw from the survey at any time and without giving a reason. The authors have not stated any conflicts of interest.

**Nonstandard abbreviations used:** AM = Armenia; AS = Asia; AT = Austria; Au = Australia; BE = Belgium; BR = Brazil; CA = Canada; CH = Switzerland; CN = China; CO = Colombia; DZ = Algeria; EC = Ecuador; EE = Estonia; EG = Egypt; ES = Spain; FR = France; GB = United Kingdom; GR = Greece; IE = Ireland; IN = India; IT = Italy; JP = Japan; L-AM = Latin America; MA = Morocco; MX = Mexico; N-AM = Northern America; NL = the Netherlands; NP = Nepal; NW-EU = Northern and Western Europe; NZ = New Zealand; OC = Oceania; pct = percentile; PK = Pakistan; PT = Portugal; S-EU = Southern Europe; SA = Saudi Arabia; SK = Slovakia; TN = Tunisia; UN = United Nations; US = United States; Veg = vegetables; WHO = World Health Organization.

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