IODINE DEFICIENCY – A PROBLEM THAT DOES NOT LEAVE HUMANITY (REVIEW ARTICLE)

ЙОДОДЕФІЦИТ – ПРОБЛЕМА, ЩО НЕ ПОКИДАЄ ЛЮДСТВО (ОГЛЯД ЛІТЕРАТУРИ)

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Abstract. Iodine deficiency (ID) is the most common micronutrient deficiency and is estimated to affect 1 billion people worldwide. Ukraine has perhaps the highest prevalence of ID in children and adolescents among European countries. Global efforts have been quite successful. Between 2003 and 2023, the number of people with iodine deficiency almost halved. Iodine, an element that is an important component of the thyroid hormones (TH) thyroxine (T_4) and triiodothyronine (T_3). The latter are crucial for the function of the liver, kidneys, muscles, cardiovascular and central nervous systems. TH regulate the overall metabolism and play a significant role in the development of the fetal and child nervous system, organ, and tissue function. For the developing fetus, iodine deficiency is one of the biggest causes of preventable intellectual disability, so the amount of iodine intake by pregnant women and women of reproductive age is a recognised international problem. Iodine is available from several food sources, but before the introduction of table salt fortification in the 1920s, deficiencies were observed in most areas, especially in regions where topsoil was depleted. Now, in most developed countries, iodine status has not been considered an important issue since the 1940s, unlike in less developed countries. Since 1990, salt iodisation programmes have been introduced and have reduced the prevalence of ID in many populations worldwide, although 30% of the world's population is currently at risk. Recently, industrialised countries such as the US, UK and EU have seen a decline in iodine intake, which may be due to changes in dietary patterns, cooking, and agricultural practices. The decline in iodine levels among women of reproductive age in these countries is of particular concern.
The purpose of the review is to study the literature on the spread of ID, which has not yet been overcome in the world in general and in our country in particular, the causes of its occurrence and impact on public health.
Keywords: iodine, deficiency, iodine-deficiency diseases, hypothyroidism, goiter, thyroid-stimulating hormone.

Анотація. Дефіцит йоду (ДЙ) є найпоширенішою нестачею мікроелементів і, за оцінками експертів, є у 1 млрд. населення планети. В Україні спостерігається ледь не найбільше поширення йододефіциту у дітей та підлітків серед країн Європи. Глобальні зусилля є досить успішними. Із 2003 р по 2023 р число населення з ЙД скоротилося майже в двічі. Йод, елемент, який є важливим компонентом гормонів щитоподібної залози (ЩЗ) тироксину (T_4) і трийодтироніну (T_3). Останні мають вирішальне значення для функції печінки, нирок, м'язів, серцево-судинної та центральної нервової систем. Гормони ЩЗ регулюють загальний метаболізм і відіграють одну із значущих партій у

розвитку нервової системи плода та дитини, функції органів і тканин. Для плода, що розвивається, йододефіцит є однією з найбільших причин інтелектуальної недостатності, якій можна запобігти, тому кількість споживання йоду вагітними та жінками репродуктивного віку є загальновизнаною міжнародною проблемою. Забезпечення йодом відбувається з кількох харчових джерел, але до початку збагачення кухонної солі в 1920-х роках дефіцит спостерігався на більшості території, особливо в регіонах, де верхній шар ґрунту виснажений. Зараз у більшості розвинених країнах світу статус йоду не вважався важливою проблемою ще з 1940-х років, на відміну від менш успішних. Після 1990 року було запроваджено програми йодування солі, які в усьому світі зменшили поширеність дефіциту йоду в багатьох популяціях, хоча наразі 30% населення світу перебуває під цією загрозою. Нещодавно в індустріально розвинутих країнах, таких як США, Великобританія та ЄС, спостерігалося зниження споживання йоду, що може бути пов'язано зі змінами в моделях харчування, приготування їжі та сільськогосподарських методах. Зниження рівня йоду серед жінок репродуктивного віку в цих країнах викликає особливе занепокоєння.

Метою огляду є дослідження даних літератури, щодо поширення ЙД, який досі не подоланий у світі в цілому й у нашій країні зокрема, причин його виникнення та впливу на здоров'я населення.

Ключові слова: йод, дефіцит, йододефіцитні захворювання, гіпотиреоз, зоб, тиреотропний гормон.

Introduction. Iodine deficiency is the most common nutrient deficiency and is estimated to affect 35-45% of the world's population to some extent. Iodine deficiency is the most common cause of goitre (ID). It is estimated that 2.2 billion people worldwide are affected by goitre. However, not all non-toxic goiters are the result of iodine deficiency. However, the incidence depends on the degree of iodine deficiency. In mild deficiency, the prevalence of goiter ranges from 5% to 20%. In moderate iodine deficiency, the incidence is 20-30 %, and in severe iodine deficiency - more than 30 % [1].

According to the findings of a systematic review (2022), Ukraine has a high level of iodine deficiency among children and adolescents. The results of subnational studies show that in Ukraine, children aged 13 to 36 months have the lowest median iodine intake (67 mcg/day) among all European countries, which is significantly lower than the WHO recommendation of 90 mcg/day for children of this age. Thyroid pathology, in particular diffuse goiter, is a leading cause of childhood endocrinological diseases in Ukraine. According to screening studies, the prevalence of diffuse goiter among school-age children in different regions of Ukraine ranges from 5.5 to 65% [2].

Global efforts have been quite successful. Between 2003 and 2023, the number of patients with iodine deficiency decreased from 2 billion to 1 billion [3].

The purpose of the review is to study the literature on the spread of ID, which has not yet been overcome in the world in general and in our country in particular, the causes of its occurrence and impact on public health.

Materials and methods. The review article is an assessment of the most important literature published in English from 1994 to 2024 that dealt with ID.

The study is a fragment of the research work of the Higher Educational Institution Lviv Medical University on the topic "Improvement of the system of circulation of

medicines during pharmacotherapy on the basis of evidence-based and forensic pharmacy, organisation, technology, biopharmacy and pharmaceutical law" (state registration number 0120U105348, term of implementation 2021-2026).

Results and discussion. Iodine is the heaviest halogen element, which mainly exists in nature in the form of iodide (I-). This form is commonly used to produce supplements and iodised table salt in the form of potassium iodide (KI) [4]. It can also be found in nature as iodate (IO_3-), another form that is also used to enrich table salt, potassium iodate (KIO_3) [4]. Iodide is naturally found in soil and seawater, which affects its content in food [5].

At the same time, in many regions of the world, including Ukraine, surface soils are depleted in iodine. Since iodide is contained in seawater, it evaporates into the atmosphere and can return to the soil [6]. In areas far from the sea or ocean, this cycle is incomplete and, as a result, plant food and drinking water become poor in iodine [6]. Historically, iodine deficiency has been observed in populations in inland regions (Central Asia and Africa, Central and Eastern Europe, and the central United States), mountainous areas (Alps, Andes, Atlas, Himalayas), and those with frequent flooding (Southeast Asia) [6]. These populations are dependent on the availability of iodised salt, so the geographical distribution of the deficit may be more homogeneous.

Iodine metabolism has the following cycle. In the human intestine, iodine is metabolised to iodide, and in healthy adults, >90% is absorbed [6]. Once it enters the circulation, it is mainly accumulated in the thyroid gland or excreted by the kidneys, with small amounts accumulating in the salivary and mammary glands [4]. Renal clearance is constant, while thyroid absorption depends on many factors. With an adequate iodine supply, thyroid uptake can be ≤ 10%, but can exceed 80% due to chronic deficiency [4]. After active transport to the thyroid gland, iodide is stored in the protein thyroglobulin (TG) before being incorporated into the molecules T_3 and T_4. These hormones enter the bloodstream where they bind to carrier proteins and are then transported to target tissues. $T_3$is the physiologically active form and binds directly to the corresponding receptors [4]. In contrast, $T_4$is a prohormone. The latter is converted to T_3 mainly in the liver and kidneys by peripheral deiodinase, which cleaves off an iodine atom. Serum thyroid-stimulating hormone (TSH) is the best marker of individual thyroid status and is used clinically for this purpose. T_3 and T_4 concentrations are not sufficiently stable and are insensitive markers of iodine deficiency and are not used for its diagnosis [4].

More than 90% of the ingested iodine is excreted in the urine by the kidneys, so measuring urinary iodine concentration (UIC) is considered one of the best biomarkers of recent dietary iodine intake [7]. The hormone TSH, secreted by the pituitary gland, is the main regulator of T_3 and T_4 metabolism through a negative feedback loop regulated by thyroid hormones and modulated by TSH-releasing hormone [4]. TSH activates the release of T_3 and T_4 into the circulation, and increases iodine absorption. Elevated TSH concentrations are usually a symptom of hypothyroidism, while low TSH levels indicate hyperthyroidism [4].

Currently, four main methods are used to assess iodine status at the population level, including CI, serum TG and TSH, and thyroid size [8]. Since blood iodide is absorbed by the thyroid gland and converted to iodothyronines or excreted in the urine, serum iodide levels alone are not used as an indicator of iodine status in individuals [9].

CSF is a sensitive marker that reflects recent iodine intake (days), whereas TS is an intermediate response (weeks to months) and changes in thyroid size reflect long-term iodine intake [4, 8]. Among individuals, CSI varies considerably daily, but this variation tends to level off at the population level, so the average value of this parameter is a better method for monitoring iodine status in populations, as discussed below [9].

Methods for determining iodine status are not equally sensitive in all subpopulations. For example, in older children and adults with iodine deficiency, TSH values do not differ from those with adequate iodine intake if the daily intake exceeds 50 mcg/day. Iodine intake below this level leads to a drop in iodine levels in the thyroid gland and, subsequently, to hypothyroidism [8].

Although serum TSH is the best indicator of thyroid function, it is not a sensitive indicator of iodine status in adults and is recommended only for neonates as an adjunct to UIC screening [10]. Similarly, it is not recommended to use thyroid hormone concentrations as indicators of iodine status, as $T_3$and T_4levels in iodine-deficient populations often remain within normal limits [4]. Serum TSH is a nonspecific marker of thyroid activity and is traditionally used as a monitoring tool in patients with thyroid cancer [10]. However, TSH determined in a dried blood sample has been used as a marker of iodine status in children [11]. In addition, a recent clinical study demonstrated the potential usefulness of TSH as a marker of iodine status in adults, as it correlates with CIU during iodine supplementation [12].

Thyroid enlargement and goitre development due to prolonged iodine deficiency can occur in infants, children, and adults as they adapt to chronic iodine deficiency. In the early stages, goiter manifests as a diffuse enlargement of the thyroid gland, and as it progresses, nodules may develop from the accumulation of new follicles, mainly in adults [8]. The size or volume of the thyroid gland can be used as a method of determining the severity of iodine deficiency. These parameters are inversely correlated with the magnitude of the deficiency when assessed in population-based data [8].

Measuring median UIC from spot urine samples of the population is the preferred method for determining iodine status at the population level and is usually expressed as μg/L [10]. Due to significant daily fluctuations in iodine excretion, the use of spot urine CI as a diagnostic tool for iodine status at the individual level is not recommended [10]. However, the daily iodine intake of a person can be calculated using an equation that includes UIC and is based on several assumptions [13]. Urinary iodine excretion can be determined over a 24-hour period (μg/day) from urine collected at a specific time or in relation to creatinine excretion (μg/g creatinine) [13]. Individual iodine status is most accurately assessed by the level excreted in the urine over a 24-hour period, and recommendations suggest using multiple 24-hour collections for reliability [13]. When assessing a population, 24-hour urine collection is usually not possible, so spot urine

levels expressed as a median in μg/L are used [4]. Typically, the use of many spot samples accounts for individual variations in urine concentration, and the median CUI is correlated with 24-hour samples [4].

A median CI of 100-199 μg/L is considered adequate iodine status for non-pregnant, non-lactating adults and children ≥ 6 years of age, while a mean CI of 150-249 μg/L is adequate for pregnant women and concentrations ≥ 100 μg/L are sufficient for lactating women and children under 2 years of age [8, 13]. Severe iodine deficiency is defined as a concentration of CI < 20 μg/l [5, 13].

The World Health Organization (WHO) defines adequate iodine intake for the non-pregnant population based on an average RDA of 100-199 μg/l, as a RDA of 100 μg/l usually corresponds to an iodine intake of 150 μg/day [8]. Data from the National Health and Nutrition Examination Survey (NHANES) for 2011-2014 show that the average IC for of the US population aged 6 years and older is 133 μg/l. The median CSI is inversely correlated with iodine deficiency characteristics, as the incidence of nodular goiter increases with a decrease in the median CSI [14].

To maintain homeostasis and hormone synthesis, the thyroid gland absorbs 50-60 mcg/day of iodine when the intake is sufficient [4]. The Recommended Daily Allowance (RDA) established by the Institute of Medicine (USA) is 90 mcg for children aged 1-8 years, 120 mcg for children aged 9-13 years, 150 mcg for men and most women aged 14 years and older, 220 mcg for pregnant women and 290 mcg for lactating women. The upper daily allowable intake for people over 18 years of age who are not receiving iodine for medical reasons is 1100 mcg. The FDA does not require that the natural iodine contained in foods be included in the food label, but iodine-fortified foods must include the % iodine [15].

In the United States in 2011-2012, 38 % of the population had a CI < 100 and were therefore classified as iodine deficient [16]. In the total US military population from 1997 to 2015, the incidence of clinically diagnosed iodine deficiency increased significantly among men, but was generally more common among women and racial minorities [17].

Hypothyroidism, a symptom of severe iodine deficiency, is present in approximately 5% of the US population. The most recent NHANES data collected in 2011-2014 showed that certain subpopulations are at greater risk of iodine deficiency [18]. Recently, it was reported that 23% of a sample of pregnant women in Michigan had an inadequate iodine intake [19].

As of 2001, the population of most European countries demonstrated mild to moderate deficiency, as 17% of the population was at risk of iodine deficiency disease (IDD) [20]. In the United Kingdom, a survey conducted in 2016-2018 showed that 17% of women aged 16-49, a particularly vulnerable group, had iodine deficiency [20].

In a study of pregnant women in Norway, the mean CI was 94 μg/L at 18 weeks of gestation, indicating that mild to moderate iodine deficiency and low iodine availability were associated with lower TSH [21]. In Southeast Asia and the Eastern Mediterranean, IDD is estimated to be present in 36% and 43% of the general

population, respectively [20]. The frequency and severity of IDD is determined by the severity of iodine deficiency. Individuals with a mild deficiency are at risk of thyroid enlargement, the formation of benign nodules with or without goiter, and the formation of endemic goiter, which occurs in certain geographic regions [14].

In adults, severe deficiency is manifested by hypothyroidism, goitre, and decreased IQ and fertility. In children, goiter, intellectual/physical developmental disabilities, deafness, and cretinism may occur [4, 22]. The thyroid gland adapts to iodine deficiency by increasing iodide uptake and intra-thyroid metabolism because of increased TSH levels, which leads to gland enlargement and goiter development [22]. This occurs at an accelerated rate in the paediatric population with severe deficiencies, and endemic cretinism is the most serious complication of iodine deficiency, characterised by a combination of intellectual disability with a neurological syndrome (neurological cretinism) or hypothyroidism (myxedema cretinism) or both. [20, 22].

The diagnosis of goitre is most often determined by the total volume of the thyroid gland using ultrasound, and nodular goitre is characterised by intra-thyroidal lesions or follicles that merge and become encapsulated [4, 14]. Multinodular goitre can be classified as euthyroid and toxic depending on the clinical presentation, epidemiology, and molecular pathology [23]. Mutations that promote thyroid cell growth can lead to organ carcinoma in multinodular goiter [23].

There are certain foods that contribute to the onset of IDD.

Women of reproductive age are one subgroup of the population in which the prevalence of iodine deficiency is increasing [8]. The increase in iodine deficiency may be related to the reduced iodine content in food. In pregnant women, severe iodine deficiency is manifested by hypothyroxinemia, elevated serum TSH, thyroid enlargement, and goiter [24]. When iodine deficiency is present in a developing fetus, it can lead to spontaneous abortion or stillbirth, increased perinatal and neonatal mortality, or congenital hypothyroidism [22]. From a public health perspective, pregnant women, fetuses, newborns, and infants are the most vulnerable groups due to the irreversible effects of IUI, which leads to brain damage and intellectual disabilities [22]. Impaired reproductive function, fetal and infant brain development are the most severe consequences of IDD [24], and low placental weight and reduced head circumference of the newborn are associated with low maternal iodine status [25]. The iodine intake requirements for pregnant women are increased due to the needs of the developing fetus and to compensate for the higher renal iodine losses seen in pregnant women. The requirements for breastfeeding mothers are even higher, as they lose an average of 114 mcg/day in breast milk to support infant growth [24]. Hypothyroidism and multinodular goitre, as well as hyperthyroidism, can develop because of iodine deficiency in mothers even after lactation has ceased due to increased iodine loss [24].

At the same time, the consequences of excessive iodine intake should be discussed. Excessive iodine status is rare and difficult to define, but a median CI of >299 μg/l indicates a possible excess. In the United States, the iodine intake is set at 1100 mcg/day for adult men and women, including pregnant and lactating women aged 19

years and older [17], although the effects of excess intake are much less harmful than those of deficiency [17].

Excessive intake of iodine can lead to hyperthyroidism, autoimmune thyroid disease and papillary thyroid cancer [24]. In healthy adults, high levels of exogenous iodine can paradoxically reduce thyroid hormone production, leading to higher TSH stimulation, causing hypothyroidism and, ultimately, thyroid growth and the development of diffuse goiter [4, 14]. In chronically iodine-deficient populations, a sudden increase and excess of iodine intake leads to iodine-induced hyperthyroidism, which mainly occurs in elderly people with nodular goitre [4]. Excessive iodine intake has been observed in Japan due to excessive seaweed consumption and in Chile, mainly in the coastal part of the country, due to excessive salt iodisation, widespread use of iodides for water purification and wide availability of iodine in the environment. Despite being a limited problem, high levels of iodine have negative health effects, so controlling iodine intake is vital.

Changes in diet and food processing technologies may contribute to the increase in iodine deficiency observed in recent decades. Foods that contain high concentrations of iodine in developed countries include bread, dairy products, and iodised salt [26]. Other foods with high iodine content are eggs, fish, and seaweed [27]. In a report, the FDA, and the US Department of Agriculture (USDA) collected and analysed more than 400 food samples from different regions to investigate the iodine content of food [27]. The analysis focused on seafood, dairy products, eggs, bread, and bakery products [27]. Dairy products and eggs were foods with a high iodine content, but their average iodine content was only 42 mcg per 100 g of sample. Plain low-fat Greek yoghurt had an average iodine content of ~50 mcg per 100 g of sample. This equates to about 75 mcg in a typical 150 gram single serving of yoghurt, which is only half the daily recommended intake for adult men and non-pregnant women. Similarly, 100 g of hard-boiled eggs contain approximately 50 mcg of iodine, which is only 25 mcg in a single 50 g hard-boiled egg. Thus, portion size should be considered when assessing the actual contribution of naturally high iodine foods to dietary intake.

On the other hand, fortified foods can contribute much more iodine in smaller portions, as observed in bread samples made with iodate dough conditioners [27], although commercial bakeries are more likely to discontinue their use [34, 35]. Data from 11 different samples of hamburger buns (50 g portion) showed an average of 598 μg of iodine per bun, almost four times the adult dietary recommendation. These samples were collected from 24 sampling sites and 4-6 different regions of the United States and chemically analysed in validated laboratories (USDA samples) or in Kansas City (FDA samples) [27].

Changes in agriculture and industry in the United States and other industrialised countries may be contributing to the decline in iodine content in food [4]. Reduced use of iodate dough conditioners may have affected the iodine content of store-bought bread and bakery products, while reduced use of iodine supplemented livestock feed may have contributed to lower iodine content in dairy milk, meat and eggs [16, 26].

Reducing the use of iodophores as disinfectants in milk processing may affect the iodine content of dairy products [27]. In addition, iodine-containing compounds used in fertilisers and irrigation affect the vegetation consumed by livestock for feed [6]. Organic food in agriculture appears to reduce the iodine content of animal feed, as iodine levels in non-organic supplementary feeds have been found to be 10 times higher than in feedstuffs [26]. Organic farming methods can significantly reduce the iodine content of organic milk.

Consumption of iodised salt is an effective health measure to ensure adequate iodine intake [8]; however, up to 20% of the iodine in salt can be lost during processing and another 20% during cooking [29]. In addition, it is a matter of concern that only 53% of table salt sold in retail stores in developed countries is iodised [30]. Lower consumption of table salt and cooking salt due to public health reports linking high sodium intake to hypertension is a contributing factor to the decline in iodised salt consumption, in addition to the use of non-iodised salt in processed and restaurant foods [27] and the increased use of sea salt, which is naturally low in iodine, compared to iodised salt for cooking [27].

Other factors that may contribute to lower dietary iodine intake include veganism and some forms of vegetarianism [30-32], which have increased significantly in popularity in industrialised countries in recent years [32]. For example, in the UK, the number of vegans quadrupled to 600,000 between 2014 and 2018, and they have lower iodine levels than the general population [16]. In addition, plant-based food alternatives such as oat milk are not usually fortified with iodine, and consumption of these products almost doubled between 2014 and 2017 in the UK [32]. In the United States, sales of plant-based products grew by 8% in 2017, and plant-based dairy alternatives are projected to account for 40% of so-called dairy beverage sales in 2018 [33]. An additional contributor to the decline in iodine levels is the increase in avoidance of dairy products, along with the emergence of plant-based milk alternatives on the market [34].

Some foods, such as soya-based alternative dairy products, interfere with iodine absorption [35]. Several alternative dairy products have been shown to contain much less iodine than cow's milk [36]. Organic farming practices in the UK contribute to a reduction in iodine content in some foods compared to conventional methods, as organic milk contains 25-40% less iodine. Data from other industrialised countries also show lower iodine concentrations in organic milk compared to conventional milk [37]. Strict requirements for limiting mineral additives in feed, standards for the number of days per year that cows must be out on pasture, a higher goitrogen content of 60% of the feed ration, and a preference for clover on pastures over nitrogen fertilisers may contribute to the lower iodine content of organic milk [37].

Dietary factors may contribute to the development of IDD, as certain foods are a source of natural goitrogens that interfere with iodine metabolism in the thyroid gland. Cruciferous vegetables (e.g., broccoli, white cabbage, cauliflower) contain glucosinolates, which have metabolites (thiocyanate and isothiocyanate) that are known to compete with iodine uptake by the thyroid [6]. The metabolism of cyanogenic

glucosides leads to the production of cyanide and subsequently thiocyanate, and this group of goitrogens is found in some vegetables such as cassava, sweet potatoes, corn, lima beans, bamboo shoots, flax, and sorghum seeds [6, 22]. Cassava is a staple food in many developing countries and has been linked to the etiology of endemic goitre in Africa and Malaysia [22]. It contains linamarin, which will produce thiocyanate if the vegetable is not soaked or cooked properly before consumption [4]. In addition, goitrogenic flavanoids in soy and millet can affect the enzymatic activity involved in iodine metabolism [6. Cooking food before consumption can minimise the goitrogens effect [4].

Labelling and regulation of iodine in foods and dietary supplements In the United States, iodine fortification of salt, infant formula and foods is regulated by the FDA, but dietary supplements, including prescription prenatal vitamins, are regulated differently than conventional foods, drugs and iodine is not a mandatory component of prenatal dietary supplements [15, 38]. However, the FDA imposes a mandatory requirement for nutrition labels on both foods and supplements. As noted earlier, manufacturers are not required to provide iodine % on the nutrition label of foods that contain iodine naturally [28]. For supplements, the FDA does not regulate ingredient standards, but under the Dietary Supplement Health and Education Act of 1994, manufacturers are required to provide ingredient information on the label; thus, if iodine is added to a food supplement, it will be stated on the label [39]. Iodine compounds that the FDA generally recognises as safe include copper iodide (CuI) and KI, which are additives to table salt; KIO3 and calcium iodate Ca (IO3)2, which are used as dough fortifiers in bread production [15]. Like the FDA, the Codex Alimentarius, created by the Food and Agriculture Organisation of the United Nations and the WHO, establishes international codes of practice and food standards (including labelling and voluntary/mandatory nutrient supplementation) to protect consumers and health, and to ensure fair trade practices in food [40]. However, the government's use of Codex standards is voluntary [15].

Iodine supplementation is an effective way to reduce iodine deficiency in a population, but precautions must be taken to prevent overconsumption. Iodine intake should be increased to a level that avoids iodine deficiency, but not higher [41]. The bioavailability of iodine from food is variable and difficult to estimate, and the interactions between different foods in the dietary matrix are not well characterised [29]. The most practical and cost-effective way to provide iodine supplementation to people with iodine deficiency is through iodised salt, according to several international organisations such as the WHO, the United Nations Children's Fund, and the International Council for the Control of Iodine Deficiency Disorders, but other approaches include the consumption of iodised water, iodised oil and iodine tablets [6]. The amount and type of iodine used for salt fortification varies from region to region, but is usually in the range of 20-40 mg iodine/kg salt. The forms that can be used for enrichment worldwide are either KIO_3, which is more stable, or KI, which has a higher iodine content and solubility [6], or sodium iodide (NaI) [42]. In contrast to salt and

water iodisation, which can cover most of the population, iodised oil or tablet supplementation is more appropriate on an individual basis and can rapidly increase iodine levels, especially in regions where salt iodisation is not possible or feasible in the short term [6].

Iodisation of all salt for human (household and industrial) and livestock consumption is the best method of combating iodine deficiency. However, it is often difficult to achieve due to poor implementation by the food and agricultural industries [6]. Global salt iodisation programmes benefit not only individuals, but also the socioeconomic status of the community. The negative effects of iodine deficiency include lower school performance, lower workforce productivity, and higher healthcare costs. Prior to iodisation programmes, the annual costs associated with iodine deficiency losses in developing countries compared to the annual costs of salt iodisation were estimated to be 70:1 [6].

Iodine supplementation programmes have been launched worldwide [41-44], but in Europe, legislation and regulation of iodine fortification varies from country to country, so regions with the highest levels of deficiency do not necessarily act.

The European region has the lowest rates of salt iodisation, even compared to countries with lower socioeconomic status [42]. Part of the reasons contributing to the low coverage are social and political changes affecting salt iodisation, in addition to increasing food globalisation [42].

In the United Kingdom, the decline in iodine status among women (adolescents, pregnant women, and women aged 16-49 years) is explained not only by the lack of iodine fortification programmes, but also by changes in agricultural practices, dietary preferences, and public health priorities. Observing programme implementation and monitoring the iodine status of the population is key to reducing population regression [42]. It is also important to avoid excessive iodine intake to correct the deficiency [41].

Lviv, Chernivtsi, Ivano-Frankivsk, Zakarpattia, Volyn, Ternopil and Rivne regions suffer from natural iodine deficiency. Mountainous areas are particularly depleted in iodine, where it rains frequently and water flows into rivers, leaching iodine from the soil. Therefore, the level of iodine in food products from iodine-deficient areas (milk, eggs, meat, cereals, vegetables) is reduced. Against the backdrop of high endemicity in the western region, the health status of the population is deteriorating due to a sharp decline in material well-being [45, 46]. The situation has been deteriorating sharply in recent years. Several factors contribute to this. These include the lack of state funding for national programmes to combat iodine deficiency, the closure and occupation of salt mines in eastern and southern Ukraine in 2022-2023, whose salt had a higher concentration of natural iodine, insufficient control over the iodisation of salt and food products at enterprises

Conclusions. Although progress has been made in many parts of the world to improve iodine status, there are still many areas and populations in need of iodine supplementation, including the United States, EU countries and Ukraine, which need to

be reached through iodisation programmes, as well as women of reproductive age worldwide.

Assessment of iodine status by measurement of CI is the optimal method, and salt fortification is the main measure to provide supplementation for the whole population. Changes in industrial and agricultural practices and dietary patterns that appear to be contributing to declining iodine levels are of considerable concern.

Changes in national legislation and the efforts of international organisations to ensure the use of iodised salt worldwide are important, as is the oversight of these programmes to ensure adequate and safe iodine intake.

Educational campaigns are crucial, especially for populations at high risk of iodine deficiency. Future research should include ongoing monitoring of iodine status in the population in addition to tracking the consumption of traditional iodine-containing foods. Studies to monitor changes in iodine content of iodine-containing foods are also important given ongoing changes in agricultural practices and cooking technology. Further research is needed to determine whether standards for the prevention of iodine deficiency diseases should be adapted and new regulatory measures developed to increase iodine intake.

Disclosure: The authors declare no conflict and/or potential conflict of interest.

Funding. The authors state, that this research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Data availability statement. The datasets analyzed during the current study are available from the corresponding author on reasonable request.

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