DOI: https://doi.org/10.21323/2414-438X-2023-8-3-172-182

Available online at https://www.meatjournal.ru/jour
Review article
Open Access

Received 18.04.2023
Accepted in revised 19.07.2023
Accepted for publication 08.08.2023

MODERN FORMS OF IODINE-CONTAINING FOOD COMPONENTS

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Keywords: *classification, iodized products, iodized salt, source of iodine, organic iodine*

Abstract
The article presents the statistics of iodine deficiency disorders and the possible causes of their occurrence. The methods of iodine deficiency correction on the basis of state programs are reviewed. The recommendations from the World Health Organization on the amount of iodine added to iodized salt are given. A review of scientific databases on the topic of iodine-containing food components of various nature and their classification are given based on the form of the components (organic or inorganic). The analysis of iodine preservation in foods incorporating iodine-containing components under various conditions of technological processing and storage has been carried out.

For citation: Dydykin, A.S., Zubarev, Yu, N., Logunova, E.I., Kuzlyakina, Yu.A. (2023). Modern forms of iodine-containing food components. *Theory and Practice of Meat Processing*, 8(3), 172-182. https://doi.org/10.21323/2414-438X-2023-8-3-172-182

Funding:
The article was published as part of the research topic No. FNEN-2019–0008 of the state assignment of the V. M. Gorbatov Federal Research Center for Food Systems of RAS.

Introduction

Iodine is an essential micronutrient for the production of thyroid hormones. Iodine deficiency may lead to negative consequences for the body, especially for women and fetuses during pregnancy as well as for children in their first years of life [1, 2]. Sufficient iodine intake is vital to ensure the normal ability of the thyroid gland to synthesize triiodothyronine (T3) and thyroxine (T4) hormones [3]. Various forms of iodine found in natural and enriched foods are used to prevent iodine deficiency [4]. Salt iodization is by far the easiest way to achieve adequate iodine intake [5], but chemical stability and bioavailability of this form is a subject for further research.

The purpose of this review was to summarize and systematize modern scientific data on various forms of iodine-containing components, as well as to classify them and analyze the possibility of their use in food products.

Objects and methods

The sources of information were 4 scientific databases: elibrary, PubMed, Scopus, Google Scholar (accessed 01/27/2023). The search strategy included the following keywords: iodized foods, iodized salt, iodine source, organic iodine, iodine enrichment, iodine deficiency correction. The following acceptance criteria for research characterization were considered: foods, biofortification, micronutrients, original research. The parameters of publications were as follows: publication since 2013, language: English, Russian. Exclusion criteria: no access to the full-text articles. Statistics on iodine deficiency prevalence are given on the basis of data from the Iodine Global Network [6, 7]. Based on the review, the authors compiled a classification of iodine-containing components, identified possible ways to enrich foods with various forms of iodine, and also established factors affecting the preservation of iodine in food products and its absorption by the body.

Iodine deficiency statistics

According to World Health Organization statistics, about 2 billion people worldwide are at risk of insufficient iodine intake and approximately one third of the population lives in iodine-deficient areas. According to the Ministry of Health of the Russian Federation, in all regions of Russia from Sakhalin to the Central regions, there is a deficiency of iodine in the diet of local residents. A number of regions of the Russian Federation affected by the accident at the Chernobyl nuclear power plant are still endemic for goiter, the main cause of which is iodine deficiency[1]. The Iodine Global Network research indicates that the level of iodine consumption by the population of the Russian Federation is “insufficient”. Consumption was estimated from the median urinary iodine concentration in school-age children (Figure 1). This technique is considered the most effective, since 90% of the consumed iodine is excreted from the body with urine [7].

[1] MU2.3.7.1064–01 “Control of the program for the prevention of iodine deficiency disorders through universal salt iodization” Guidelines, Moscow: Ministry of Health of the Russian Federation, 2001. Retrieved from https://docs.cntd.ru/document/1200026360 Accessed March 11, 2023

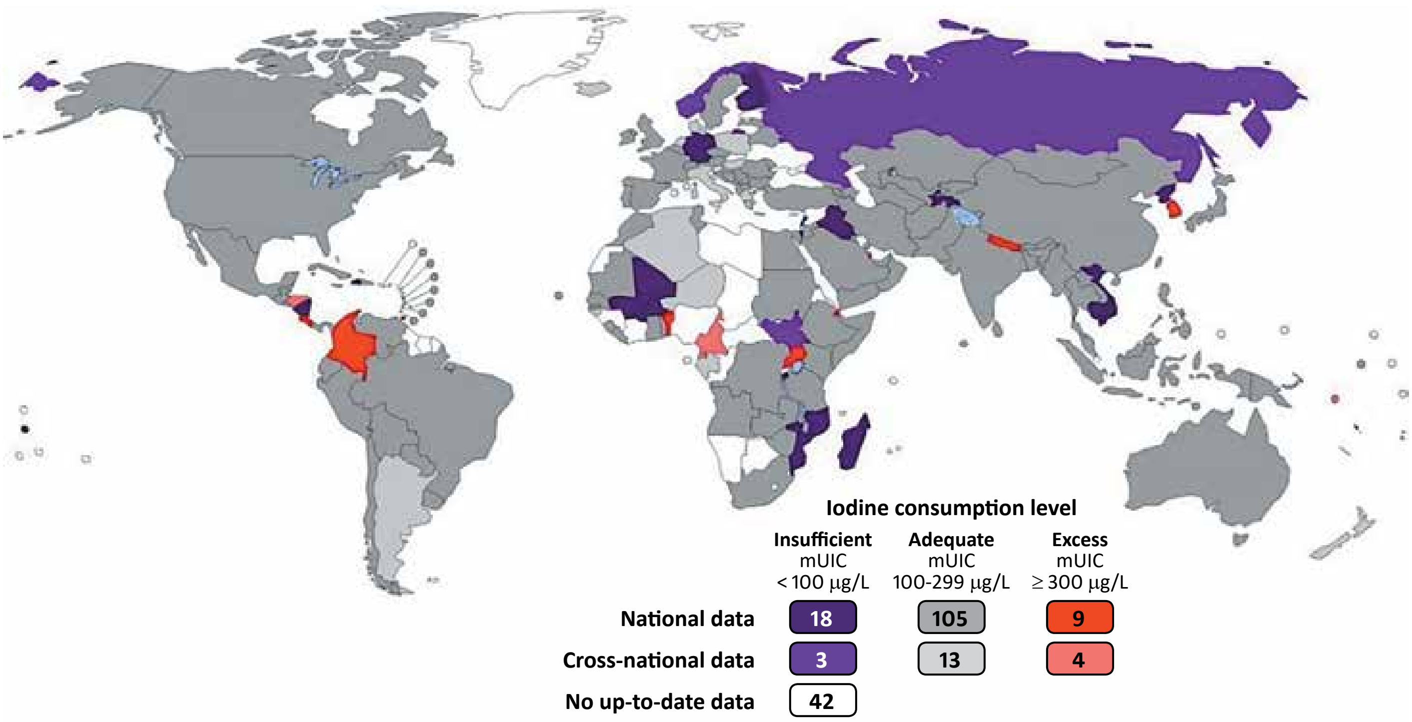

Figure 1. Global iodine consumption research 2005–2020 [8]

Iodine deficiency may interrupt biological functions and cause the development of endocrinological diseases such as goiter, hypothyroidism and cognitive impairment. A study by the National Research Center for Endocrinology of the Ministry of Health of the Russian Federation showed that annually, 1.5 million adult patients and 600 thousand children with endocrinological disorders receive medical care in the Russian Federation [9]. In monetary terms, the cost of treatment exceeds 250 billion rubles, which is 5 times more than the amount needed to organize measures to prevent all iodine deficiency disorders in the Russian Federation. The level of actual iodine consumption by people in Russia is 40–80 μg per day, which is 3 times lower than the established values of physiological need[2].

The growing interest in alternative products also reduces the level of iodine consumption by the population, since the raw materials for them do not contain the required amount of iodine, and only a small part of such products are additionally enriched [10]. Seaweed is often present in the diet of vegetarians, but this is often not enough to meet 100% of the need for iodine. According to the authors of [11], pescetarianism among people who do not eat meat implies the consumption of fish and seafood, which significantly increases the chances of such people to intake the necessary amount of iodine with food.

According to the strategy for improving the food quality in the Russian Federation until 2030[3], the development of methods for justification the shelf life of food products is a priority, as well as assessing the preservation of essential foods and biologically active substances. It should be noted that the preservation and absorption of iodine from foods depends on the form of iodine, technological modes of processing and storage conditions of finished products.

Methods for iodine deficiency correction

Currently, the problem of iodine deficiency is solved mainly by the introduction of iodized salt into the diet. In 2021, the Ministry of Health of the Russian Federation developed a draft federal law "On the prevention of iodine deficiency disorders"4, which established the measures for the prevention of iodine deficiency disorders, such as the use of iodized salt in food manufacturing and for salting, establishing requirements for the placement of iodized salt and products containing it at the point of sale, fortification of foods with iodine, as well as informing the population about iodine deficiency consequences and ways to prevent them. In addition, part 3 of article 6 of this draft federal law provides for the use of iodized salt in the manufacture of food products, except in cases where the technological process does not allow this. In this case, the products should be enriched with iodine by other possible methods.

Salt iodization programs have been adopted in 125 countries around the world (including Russia), but due to the salt reduction strategy, it is difficult to combine these two policies. Reducing the sodium content in food is implemented in 44 countries around the world [6]. The

[2] Draft federal law dated April 12, 2021 «On the prevention of iodine deficiency disorders», Ministry of Health of the Russian Federation. Retrieved from https://regulation.gov.ru/Regulation/Npa/PublicView?npaID=99202, Accessed March 11, 2023

[3] Strategy for improving the food quality in the Russian Federation until 2030 (approved by the order of the Government of the Russian Federation dated June 29, 2016 No. 1364-r) Retrieved from https://docs.cntd.ru/document/420363999, Accessed March 11, 2023

[4] Draft federal law dated April 12, 2021 «On the prevention of iodine deficiency disorders», Ministry of Health of the Russian Federation. Retrieved from https://regulation.gov.ru/Regulation/Npa/PublicView?npaID=99202, Accessed March 11, 2022

World Health Organization (WHO) promotes both the implementation of salt reduction programs as one of the cost-effective strategies for reducing the level of nutrition-related diseases, and universal salt iodization for the prevention and control of iodine deficiency disorders [13].

Salt iodization programs need to be constantly monitored to adjust the amount of iodine added to salt and to control the sodium intake in the population. Iodine loss depends on the iodization process, salt quality, packaging materials, and external factors. Given these conditions, WHO proposed to set the level of iodine added to salt as 65 mg of iodine per 1 kg of salt (Figure 2). Sodium carbonate/bicarbonate and sodium thiosulfate or dextrose are also added to the salt to stabilize the iodine.

The indicated concentration (Figure 2) was calculated based on the average recommended nutrient intake, i. e. 150 µg iodine/day + 30% process losses, considering iodine bioavailability of 92%. Iodine loss is variable depending on processing and storage conditions. The policy of the Food and Drug Administration (FDA), in close collaboration with WHO, supports the reasonable fortification of foods with additional nutrients, depending on the goal: 1) correction of recognized nutritional deficiencies; 2) restoration of the initial nutrient concentrations; 3) maintaining a balanced nutrient-versus-calorie profile; 4) improving the nutrition quality. In this regard, FDA has set a maximum amount of potassium iodide for use as a supplement in salt of 0.01 wt.% [14] to prevent the consequences of excess iodine in the diet.

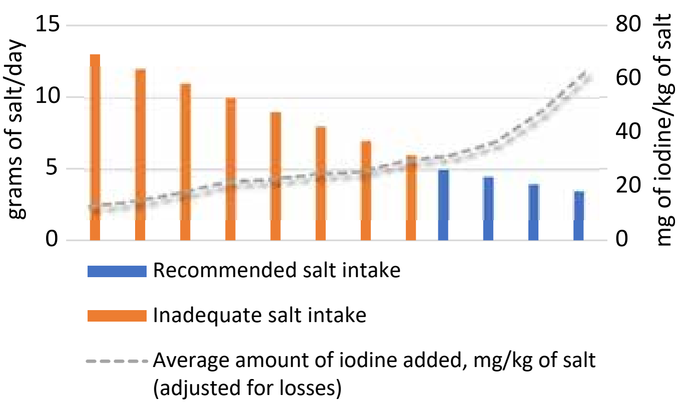

Figure 2. WHO recommended concentrations for salt fortification with iodine [12]

An alternative way to ensure sufficient iodine for the population is consuming foods rich in natural iodine or containing an organic form of iodine. Diversification of the diet with more seafood may be effective, but not always possible due to the high cost of such products. In the production of iodized products, it is necessary to ensure iodine level control throughout the entire shelf life due to the high volatility of iodine compounds. The effective use of iodine-enriched foods for iodine deficiency correction in the population is possible providing regulation by state, departmental and manufacturing control of the production and sales of enriched foods and iodized salt.

Components containing naturally occurring iodine

High concentrations of naturally occurring iodine are found in seafood [4] and seaweed [15] due to their ability to accumulate iodine from sea water. Eastern countries have long used seaweed as a source of iodine [16], and in the last 10 years this trend has begun to develop in Europe. At the same time, Europe allows products on its market that are safe for consumption and regulate their sales. For seaweed, France first established a regulation regarding their use as a food source in 1997, called "Novel Food", which includes a guideline for the evaluation of 25 algae and 3 microalgae suitable for human consumption [17].

A study by Norwegian scientists on brown and red algae of the North Atlantic showed that the consumption of 32 to 2150 mg of them in dried form completely meets the need for iodine in adults [18]. In addition, iodine content in these algae does not depend as much on season as in algae collected in the Pacific Ocean along the coast of China, as mentioned in the publication of Chinese researchers [19]. The effect of thermal processing on different types of algae is ambiguous, since in one case, boiling reduces iodine concentration, and in other case, it has no effect, which was proven in the study of four seaweed types [20]. Apparently, this is due to the impossibility of releasing iodine from its organic form in certain types of algae by thermal dehydration.

The study of numerous databases containing information on the amount of iodine in fish allows to conclude that it predominates in naturally grown cod, pollock, and hake [21]. A search for scientific publications on this topic showed that the average iodine content in fish fillets varies from 21 µg/100 g in raw Atlantic halibut to 790 µg/100 g in raw pollock [22] and depends on the geographic range. Iodine content in fish depends also on the season and spawning period. A study by Norwegian scientists [23] showed that fatty fish accumulate less iodine than non-fatty ones. Biofortification of aquaculture products with iodine is carried out by using feed supplements in the diet of fish and shellfish [24], as well as by integrating aquaculture products (seaweeds) into feed [25]. This method of animal products enrichment with iodine is called "antemortem formation of the functional properties in raw materials".

Eggs are also a source of iodine, as animal feed is enriched with calcium iodate, similar to fish feed. Initially, calcium iodide and calcium iodate were used to increase the productivity of farm animals, but later it was found that iodine is able to accumulate in animal tissues and remain in them until processed food is consumed. The authors of the article [26] studied the transfer of microelements and macronutrients into the egg from feed consumed by laying hens. Scientists claim that one egg of 60 g from laying hens who consumed iodine-containing feed supplements contains up to 122 µg of iodine. At the same time, bioavailability of iodine for the human body is higher when the feed supplements contain iodine in an organic form, i. e. in the form of iodized milk proteins. Since eggs, as well as milk, are mandatory for inclusion in the diets of certain population groups for which iodine plays a crucial role in ensuring the growth and development of the body (pregnant, lactating women and children), the amount of iodine in them should be standardized. In addition, the amount of iodine in chicken eggs may vary depending on animal metabolism adaptation to enriched feed and the age of the animals [27].

In the organic method of milk production, animals are fattened on pastures without the use of feed supplements, which means that the animal does not receive a sufficient amount of many nutrients. There are studies proving that iodine concentrations in organic milk are much lower than in regular milk [28, 29], since the organic method of fattening does not involve the use of iodine-containing premixes. Further, iodine content in milk depends on season [30] and the method of milk thermal treatment at a dairy plant [31, 32]. In addition, for disinfection of the milking system and udder in the production of non-organic milk, a solution of iodofluorine is used, which is a chemical contaminant in dairy products [33] and, accordingly, increases the concentration of iodine in milk.

Higher plants, as a rule, are not a source of iodine. However, biofortification of agricultural crops is one of the promising ways of iodine deficiency correction due to the high level of consumption and large cultivated areas. Iodine is introduced into plants in various ways: through the soil with fertilizers, as well as with the help of hydroponic and irrigation systems [34]. To enrich plants, the method of root feeding with fertilizers containing inorganic forms of iodine (KI and KIO_3) is more often used. A comparative analysis of these two substances as fertilizers by Polish and Hungarian scientists showed that KI is more effective and does not have an inhibitory effect on crop growth [35, 36]. When iodine compounds are absorbed through the root system, its concentrations decrease from the root to stems, leaves, and fruits, which was proved in the study by Italian scientists [37], so it is advisable to use this method for enrichment of leafy vegetables. It is worth noting that the method of foliar fertilizing with solutions containing iodine is more suitable for mature plants of leguminous crops.

Iodized salt

Iodized salt is a mechanical mixture of salt (NaCl) and inorganic iodine compound, potassium iodide (KI) or potassium iodate (KIO_3). The disadvantage of this form is the low resistance to light and moisture, as well as the high volatility of iodine [38]. Studies by Russian scientists have shown that the content of inorganic iodine in foods containing iodized salt decreases by 50% after storage for 20 days from the date of production [39]. According to studies on the stability of iodine in the form of iodized salt under various processing conditions [40], a decrease in the iodine content in food products occurs due to moisture loss when heating.

The content of iodine in iodized salt depends on the specific manufacturer, conditions and term of storage. The World Health Organization has set a safe level of salt intake of up to 5 g/day for the adult population. The recommended intake of iodine is 150 µg /day for adults [41]. An analysis of sufficient iodine levels supply in different countries of the world, provided that all salt in the diet is iodized and adjusted for a 30% loss of iodine in the product during storage and cooking is presented in Table 1.

Table 1. Levels of iodine consumption with iodized salt in different countries [42]

Country	Iodine concentration in iodized salt, mg/kg	Iodine content in 5 g of iodized salt, taking into account losses (30%), µg	Level of iodine supply to the body when using 5 g of iodized salt, % of the daily requirement *	Actual level of iodine consumption with food for 2021, % of the daily requirement *	Actual level of iodine supply to the body for 2021, µg/L **
Canada	77	270	180	189	126
USA	76.5	267	178	190	127
Spain	60	210	140	173	115
South Africa	50	140	93	130	87
Russian Federation and CIS countries	40	140	93	<100	67
Italy	33	116	77	118	79
Brazil	30	105	70	276	184
Egypt	30	105	70	170	113
Greece	30	105	70	132	88
Thailand	30	105	70	179	119
UAE	27.5	97	65	162	108
China	26.5	93	62	200	133
India	25	88	58	178	119
Switzerland	25	88	53	137	91
Poland	23	81	54	112	75
Germany	20	70	47	89	59
Turkey	19.5	69	46	107	71
Indonesia	18	63	42	215	143
Australia	17.5	62	41	175	117
France	17.5	62	41	136	91
Serbia	15	53	35	195	130

* Recommended level of iodine supply to the body of an adult healthy person is 150 µg/day. This value was calculated by population survey.

** Actual intake was measured by median urinary iodine concentration. Data provided by the Iodine Global Network for the period of 2006 to 2021 [43].

The data presented in Table 1 indicate that the level of iodine supply to the body does not always depend on iodine concentration in salt. Obviously, this is directly related to the content of iodine in raw materials depending on the region of cultivation and indirectly related to the food preferences of different peoples of the world, as well as the level of consumption of iodine-enriched foods. For example, in Brazil, China, Indonesia, and Serbia, the actual level of iodine supply to the body is several times higher than the theoretical level when using iodized salt. This means that other sources of iodine are present in the diet of the population, including natural and enriched ones.

Considering the relatively high consumption of bakery products by Russians in comparison with Western countries, i. e. USA, Australia, and New Zealand, the production of functional bakery products using iodized salt is promising in terms of iodine deficiency correction the Russian Federation [44]. In addition, the use of iodized salt improves sanitary and microbiological safety of bakery products, preventing the development of molds and *Bacillus mesentericus* [45]. However, the inorganic form of iodine is unstable and iodine loss during the technological processing and storage reaches 50% already on the ninth day of the finished product storage, which is reflected in the study of sausages and bakery products with the addition of iodized salt [46].

Considering the fact that iodized salt is now used for industrial purposes mainly in the production of bakery products, and its loss during storage reaches 50%, meeting the need of 150 μg/day with the use of adequate bread amounts is difficult. It is reasonable to develop recipes for other processed food products containing iodized salt or other ingredients rich in iodine. However, this requires the discussion and agreement of the technology with food manufacturers and the study of iodine preservation in its various forms under various technological regimes and during storage [47]. In addition, the loss of iodine during storage from iodized salt reaches 70%, which significantly reduces the level of iodine supply to the body when consuming 5 g of salt per day. Salt iodization programs are widely accepted all over the world, but legal regulation differs depending on the country [48] and therefore not all iodine-deficient regions take appropriate actions.

Iodine-containing components

In addition to potassium iodate and potassium iodide, the food industry uses iodine-containing supplements based on organic carriers: amino acids, fatty acids, and polysaccharides. Currently, the most common is iodine compound with milk protein, i. e. iodocasein, which is also used as Bioiodine dietary supplement. To obtain casein, cow's milk is defatted and the casein protein fraction is isolated by standard methods [49]. Elemental iodine is used for iodization. During the reaction, the temperature, pH of the medium, and the required degree of iodization are controlled. Iodine ions are linked to the amino acid tyrosine, which is a part of the casein structure, by the mechanism of electrophilic substitution. Iodine acquires an oxidation degree of +1 and forms a strong bond with carbon [50]. A solution of iodized protein is sterilized by short-term heating up to 90 °C, and then dried and ground to obtain a powder. The content of iodine in the Bioiodine dietary supplement is 7% to 9%, and the analysis of its preservation during technological processing and storage as a part of food products showed higher values in comparison with iodized salt [51].

The aforementioned milk protein-based supplement is successfully used in the production of fermented milk products with functional properties, such as cottage cheese [52] and yogurt [53]. In addition, Bioiodine may be used without reducing the effectiveness in relation to the normalization of the iodine index in the formulations of the products based on meat raw materials, which was proved in a study involving 20 students of the "Oryol State Institute of Economics and Trade" [54]. According to *in vivo* studies, its use is most effective in preventing destructive and degenerative changes in different organs [55]. Iodocasein is recommended by the Ministry of Health of the Russian Federation for preventing iodine deficiency disorders, particularly as a supplement when fortifying baby food. However, the production of this supplement is carried out according to technical specifications, and so far, no common standard that establishes general requirements and quality indicators is developed.

Iodized elastin is a hydrolyzate of elastin from connective tissue enriched with iodine by adding potassium iodide in the amount of 50 to 200 μg per 1 g of elastin. According to the data presented in the patent[5], raw elastic tissue is able to bind up to 70% of the of the iodine introduced, while iodine binding in the fine-cut boiled nuchal ligament reaches 100%. Iodized elastin hydrolyzate is incompatible with the technologies for whole milk, fermented milk products, and drinks production, but may be successfully used in meat products. The reliability of iodine delivery to the thyroid gland was confirmed by *in vivo* experiments on laboratory animals [38] using a blood test for the level of thyroid hormones as a result of artificial hypothyroidism simulation for 14 days.

Production of iodized soy protein involves the enrichment of the carrier (soy isolate or soy flour) with iodine by soaking in a potassium iodide solution under conditions of limited lighting for 30 minutes. Binding of iodine in this case reaches 480 μg of iodine per 1 g of soy protein, while high stability of iodine in the form of dietary supplements is observed during storage for 12 months [56]. The authors [57] also proved the effectiveness of this supplement against experimental hypothyroidism by the *in vivo* method. This technology has not yet been applied in practice, but is promising in the production of meat products. The properties of iodized soy protein were studied [38] in comparison with iodized wheat fibers and iodized salt. These studies also showed that the stability of iodine bound to soy proteins during storage under various temperature and humidity conditions is much higher than in iodized salt.

Iodine-chitosan is a dietary supplement containing iodine linked to an amino polysaccharide of animal origin,

[5] Bitueva E. B., Zhamsaranova S. D., Kapustina Yu. A. Biologically active food supplement. Patent RF no. 2266021, 2004. (In Russian)

i. e. chitosan. Iodine-chitosan is obtained using absorption of iodine from water-alcohol vapors of potassium iodide and potassium iodate by chitosan powder [58]. The result is a supplement containing inorganic iodine stabilized in an organic matrix. This supplement may be successfully introduced into the formulations of fermented milk products [59]. Studies of iodine preservation during the storage of products containing iodine-chitosan have not been carried out, but similarly to Bioiodine and iodocasein, it may be concluded that this form of iodine has a high resistance to external factors, and therefore is stable. The use of iodine-chitosan in the diet of laboratory animals with hypothyroidism activates the formation and maturation of blood cells, and *in vitro* studies prove its antioxidant properties [60].

Phytoiodine is a dietary supplement containing iodine in an organically bound form with a plant-based polysaccharide pectin. According to the data presented in the article [61], the production of Phytoiodine involves the introduction of pectin into iodine solution, thorough mixing and drying at room temperature. The author of the dissertation [62] proved the biological effectiveness of iodine-pectin compounds in terms of the impact on the main factors in the pathogenesis of endemic goiter and goiter transformations. This supplement is successfully used in the production of specialized enriched dairy products at canned milk plants in Bashkortostan [63]. High Phytoiodine stability during heat treatment and storage was proved by an experiment with adding it to bakery products and subsequent quantitative analysis of iodine [64].

Preparation of iodized flour from wheat germs is described in [65] and involves the germination of grains in an aqueous solution of potassium iodide under conditions of limited lighting for 30 minutes, then drying at a temperature not exceeding 60 °C and grinding. In this case, high stability of iodine is observed during storage for 12 months. Sprouted wheat enriched with iodine may be used in the production of boiled-smoked sausages, which is reflected in the study of Russian scientists [66]. Western colleagues also conducted studies of this ingredient, which proved a high degree of iodine preservation in wheat dietary fibers compared with iodine preservation in the composition of iodized salt when stored at different temperature and humidity conditions for 12 months [38].

Substances of a carbohydrate nature may also act as a carrier for molecular iodine: sugars, dietary fibers and starches. Iodized arabinogalactan is obtained by introducing hydrated elemental iodine in the amount of 200 μg per 100 g into a solution of polysaccharide extracted from coniferous wood. This supplement has emulsifying and stabilizing properties, which makes it possible to use it in the production of iodized minced semi-finished products based on meat raw materials. However, iodine losses during storage of chilled semi-finished products containing it reach 48% within 24 hours after production [67].

Rebaudioside A iodization with the formation of iodine-glycoside described in the patent[6] involves mixing with molecular iodine in distilled water at high temperature and drying in a desiccator. The supplement contains 12% of iodine, and IR spectroscopy studies of the iodine-glycoside conjugate indicate the inclusion of iodine molecules in the structure of rebaudioside A molecules [68]. Studies of iodized rebaudioside in an experiment with laboratory animals showed that the use of the supplement compensates for the negative effect of mercazolil on parent rats [69], and therefore has a positive effect on cognitive functions in rat pups with artificial hypothyroidism. This supplement has not yet been applied in practice, but the physicochemical properties of low molecular weight carbohydrates open up broad prospects for their use in the food industry.

Iodized peanut butter is obtained using esterification of unsaturated fatty acids by linking iodine to double bonds [70]. The high efficiency of iodized peanut butter in the prevention of iodine deficiency disorders in comparison with iodized salt was proven 30 years ago by foreign scientists in experiments involving Algerian school-age children [71] and young people living in Zaire [65]. However, this supplement has not yet been applied in practice in food industry.

Foods containing added iodine

Iodization of food products may also be a part of the technology for processing raw materials into a finished product. Iodine is introduced in organic and inorganic form, most often as a component of salt or dietary supplement, since in this case it is easier to control the final iodine content in the product. This method of enrichment is applicable to products that undergo a technological mixing operation, for example, for bakery and confectionery products, pates, mousses and purees, minced meat products and sausages.

Since iodine is a highly volatile substance, its preservation may be affected by extreme technological regimes and storage conditions [72]. For the effective use of the above additives in food production, it is necessary to establish the levels of iodine preservation under various processing conditions and shelf life of products with supplement. The analysis of the literature presented in this review makes it possible to compare the degree of iodine preservation when it is added to products undergoing heat treatment. Storage period for various food products has a fairly wide range and comparison of iodine preservation in them should be made based on the shelf life for each individual product. Comparative analysis of iodine losses in the composition of finished food products containing iodized supplements is presented in Table 2.

[6] Kamilov F. Kh., Konkina I. G., Murinov Yu.I., Ivanov S. P., Baiburina G. A., Kozlov V. N. et al. Iodine-containing biologically active food supplement. Patent RF no. 2716971, 2019. (In Russian)

Table 2. Iodine losses during heat treatment and storage

Name of the iodine-containing component	Food product containing iodized component	Heat treatment conditions	Loss of iodine during heat treatment	Loss of iodine by the end of the shelf life of the finished product containing the dietary supplement*	Duration of product storage	Data source
Iodized salt	Sausages	85 °C	35.9%	More than 70%	20 days	[39, 51]
Bioiodine			12.2%	20.7%	21 days	
Iodocasein			3.2%	52.5%	21 days	
Iodized elastin	Dietary supplement	—	—	44%	6 months	[38]
Iodized soy protein	Minced meat products, steamed, frozen	100 °C	7%	54%	150 days	[38]
Iodized dietary fiber derived from wheat			3%	47%	150 days	[38, 66]
Iodine-chitosan	N/a					
Phytoiodine	Bakery products	220 °C	—	4%	90 hours	[64]
Iodized inulin			—	up to 80%	30 days	[73]
Iodine-glycoside	N/a					
Iodized arabinogalactan	Minced meat products, steamed, chilled	100 °C	0%	40%	24 hours	[67]
Iodized butter	N/a					

* data over the past 10 years for the studies published in scientific journals.

The data in Table 2 support the expediency of using iodine-containing supplements and biologically active additives in the production of mass consumption foods instead of iodized salt due to the high degree of iodine preservation during technological processing and storage of finished products. This will reduce the amount of added salt in the diet and increase the amount of iodine consumed with food. Apparently, resistance to high temperatures and external conditions during storage is inherent in iodine-containing supplements of an organic nature, i. e. linked to macronutrients: amino acids and polysaccharides, due to more stable iodine-carbon bonds.

Conclusion

Currently, salt iodization is the main method of iodine deficiency correction. However, salt intake should be limited to 5 g per day. This is especially true for those groups of the population for which iodine is a vital element that comes with water and food: pregnant and lactating women, young children. According to IGN (Iodine Global Network) statistics, the degree of iodine supply of the population does not always correlate with iodized salt consumption. The best way to fortify the diet with iodine is to eat natural sources of iodine such as milk, eggs, seafood, and seaweed, but often the amount of iodine from these foods is insufficient.

Foreign and domestic scientists have developed a number of iodine-containing foods and supplements that have the potential in the production of industrially processed iodized functional foods. The authors have classified the iodine-containing ingredients based on the form of iodine (organic/inorganic).

In the technology of processed food products, iodine is used mainly in the form of chemical compounds of various nature: salts of hydroiodic (iodide) and iodic (iodate) acids, amino acid derivatives, organically bound iodine with polysaccharides, as well as fatty acids esterified in the presence of iodine. As mentioned above, organic forms of iodine are more stable during storage, and also have high bioavailability and low toxicity compared to inorganic forms of iodine. These properties characterize the organic form of iodine as more suitable for the production of baby foods [54], as well as therapeutic, preventive and functional products in comparison with the inorganic one.

Iodine-chitosan is also included in the group of inorganic forms of iodine, since in this case, iodine is in the inorganic form of KI enclosed in a chitosan matrix. In addition, there are developments of iodized fatty acids, but since their use in food production has not been tested even in laboratory conditions, the authors considered it incorrect to include these substances in the classification of food components.

An analysis of scientific and technical literature allows to conclude that iodine-containing ingredients are logically divided into organic and inorganic ones (depending on the form of iodine present in the supplement). The form of iodine directly depends on the method of enrichment and, in this regard, the authors have compiled a hierarchical diagram that reflects the classification of iodine-containing ingredients (Figure 3).

Each mentioned iodine-containing ingredient is characterized by individual resistance to heat treatment and storage conditions. Based on the literature review, the authors concluded that organic forms of iodine are more resistant to technological conditions.

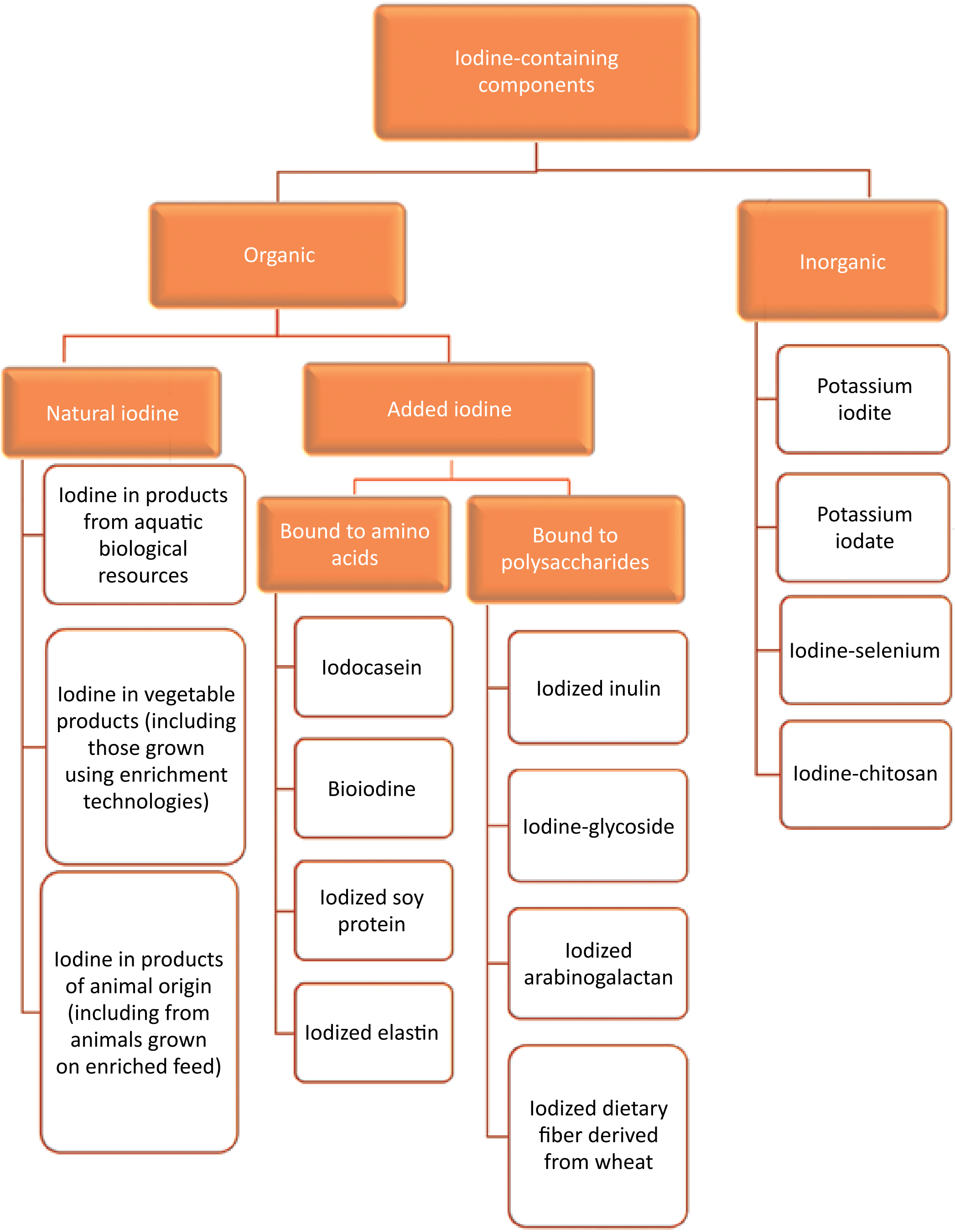

Figure 3. Classification of iodine-containing components proposed by the authors

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The authors declare no conflict of interest.