Research Article

The Use of BrownAlgae Laminaria Saccharinain Iodine Enriched Products Aimed at PreventingIodine Deficiency

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Abstract. The high content of iodine in dried algae has allowed it to be used as a physiologically functional food ingredient in the technology of fortified foods, which can help prevent iodine deficiency. The aim of this research was to develop a technology for food products enriched with iodine (Italian crispbreads), as well as fermented dairy products (thick and drinking yoghurts with various fruit fillings). The brown algae *Laminaria saccharina*, which originates from the islandFrøya (in Norway), was used to enrich the products with iodine. This algaewas grown on the farms of the company "Energy Solutions AS" and was dried by various methods of low-temperature drying (heat pump at a temperature of minus 10 °C, drying in 1-3 layers; vacuum freeze drying with pre-storage at a temperature of minus 8 °C; and pre-freezing and storing at a temperature of minus 25 °C for 2-6 days). The chemical composition of the algae was studied. The findings showed that the modes of pretreatment of algae and the method of cold drying did not influence the following indicators (in % of the total mass of dried algae): the mass fraction of water (6.00±0.50% to 6.93±0.50%),ash (46.40-50.14%), andsodium chloride (31.00±1.75%). The above technological factors substantially affected the content of protein and iodine in the dried algae. Thus, the mass fraction of protein varied from 5.88% to 12.35% per total mass, and iodine varied from 0.367% to 0.522% in terms of dry matter. The optimal dosage of dried algae for adding to raw material was calculated (which provided anabove-stated iodine content of % of the recommended level of adequate consumption in 100g of the developed products): from 66% in crispbreads to 88% in fermented dairy products. All new products provided a high level of organoleptic evaluation.

Keywords: brown algae, *Laminaria saccharina*, iodine, functionalproduct, crispbreads, drinking yoghurts, thick yoghurts

1. Introduction

The modern human lifestyle is characterized by low physical activity, as well as a lack of vitamins, minerals and nutrients in the daily diet. The latter is caused by a decrease in the amount of food consumed in an effort to maintain a stable and healthy weight, as well as social and environmental conditions, and an unbalanced diet. As a result, there is an increasing demand for affordable products enriched with valuable biologically active substances that can reduce the risk of developing many diseases and have a beneficial effect on health.

One of the most pressing problems of an unbalanced diet is iodine deficiency. According to theIodine Global Network, in 2017, 19 countries were classified as countries with insufficient iodine consumption among the population. In this list, Russia ranks third and does not have territories free of iodine deficiency. According to statistics of the National medical research center of endocrinology of the Ministry of Healthcare of the Russian Federation, as of the beginning of 2018, the actual average consumption of iodine by a resident of Russia is three times less than the lower threshold norm set by the World Health Organization (from 150 to 250 mcg) and is only 40 to 80 mcg per day. At the same time, more than 1.5 million adults and about 650 thousand children with thyroid diseases, the main cause of which is a lack of iodine, need specialized endocrinological care every year. In conditions of iodine deficiency, the risk of developing thyroid cancer and other serious diseases increases [1].

However, diseases caused by iodine deficiency can be effectively prevented by consuming sufficient amounts of iodine, primarily in the composition of fortified and functional foods of mass demand, primarily iodized salt, as well as bread and bakery products, pasta and other products.

One of the main objectives of the state policy in the field of healthy nutrition of the population is to improve the quality, expand the range and increase the volume of products. Order of the Government of the Russian Federation of October 25, 2010 N 1873-R "On the basics of state policy in the field of healthy nutrition of the population of the Russian Federation for the period up to 2020" is aimed at solving this problem, including by increasing the share of production of mass-consumption products enriched with vitamins and minerals to 40-50% of all food produced in the country [2].

Fermented milk products and flour products are a traditional element of Russian food. Enriching the composition of this group of products with iodine will contribute to the formation of a sustainable preventive effect in the population against diseases caused by iodine deficiency.

Takinginto account the above-mentioned, the actual goal of the study is to develop a recipe and technology for iodine-enriched mass-use food products – drinking and thick yoghurts, as well as very popular among fans of a healthy lifestyle low-calorie flour crispbreads. As a source of physiologically functional food ingredient iodine, it is proposed to use dried brown algae, Laminaria Saccharina.

2. MethodsandEquipment

2.1. Methods

2.1.1. Organoleptic methods

The determination of organoleptic properties of products was carried out by means of extended tasting by specialists using the developed scales, the results of tasting after statistical processing were presented in the form of profiling programs.

2.1.2. Physic-chemical methods

- mass fraction of water, fat and ash (mineral matter)in dried algae, crispbreads and yogurt – by weight method;

- mass fraction of total nitrogen (TN) and nonprotein nitrogen (NN) in fermented milk products (drinking and thick yoghurts) andcrispbreadswere determined by Kjeldal method on Selecta Bloc Digest apparatus and Pro-Nitro A unit; before mineralization in the sample, trichloroacetic acid (TCA) protein deposition was carried out on NN with subsequent filtration;

- protein content incrispbreads and yogurt was found by multiplying the difference between TN and NN by 6, 25;

- mass fraction of total nitrogen (TN) in dried algaewas determined by Kjeldal method on Selecta Bloc Digest apparatus and Pro-Nitro A unitaftermineralization in the sample;

- protein content in dried algae was found by multiplying the TN by 5.3;

- mass fraction of iodine in dried algae was determined by colorimetric method, which is based on the formation of a colored complex compound of iodine with sodium nitric acid in an acidic environment and colorimetric determination of it;

- mass fraction of carbohydrates in dried seaweed, crispbreads and yogurt – bycalculationmethod;

wettability of crispbread was determined by the method based on the establishment of an increase in the mass of crispbreads when immersed in the water at a temperature of 20°C for a certain time (wettability is characterized by the ratio of the mass of products after getting wet to the mass of dry products and is expressed as a percentage);

- the titrated alkalinity of thecrispbreadswas determined by titration (in the experiment, for degrees of titrated alkalinity the amount of cubic centimeters of a solution of hydrochloric or sulfuric acid was taken with a concentration of 1 mol per

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cubic decimeter; it is the amount necessary to neutralize the alkaline substances contained in 100 g of the product).

2.1.3. Microbiological methods

Safety indicators of products and the number of living microorganisms in yoghurts were determined in accordance with the regulatory documents of the Russian Federation (Technical Regulations of the Eurasian Economic Union TR EAES 040/2016) by standard methods.

2.1.4. Mathematical methods

The results of the experiments were processed using standard statistical methods via Excel, and the optimal recipe composition of products was determined using the Fuzzy Logic Toolbox module included in the MatLab package [5].

3. Results

From 2015 to 2018, Murmansk State Technical University (Murmansk, Russian Federation), together with the Norwegian Technical University of Trondheim (NTNU Norwegian University of Science and Technology, Department of Energy and Process Engineering)participated in the Russian-Norwegian research project "Sustainable energy in food production", funded by SIU Foundation for cooperation of Circumpolar States. One of the research project of this collaboration was a project to study the functional and technical properties and promising technologies for processing the mariculture object(brown algae LaminariaSaccharina from Frøya island, Norway, grown on the farms of the "Energy Solutions AS" company).

The objects of the study were Laminaria Saccharina algae collected on farms and subjected to pre-treatment and low-temperature drying in various versions for canning purposes. Samples of dried algae subjected to treatment were examined:

- algae without pre-storage, heat pump drying at a temperature of minus 10 °C in a single layer;

- algae without pre-storage, heat pump drying at minus 10 °C in three layers;

- algae after pre-storage at a temperature of (8±2) °C for 2, 3 and 4 days, dried by vacuum drying ;

- algae after pre-freezing and storage at a temperature of minus 25±0.1°C for 2, 3, 4 and 6 days of storage followed by vacuum freeze drying.

In addition to dried laminaria, the objects of research were experimental samples of food products enriched with iodine by adding the algae in its composition, which were made according to developed technologies and recipes.

Table 1 shows the most significant results of the study of the composition of dried kelp, depending on some of the pre-treatment and low-temperature drying modes used.

Microbiological safety studies of all studied laminaria samples in polymer sealed packaging without vacuum showed that the number of mesophilic aerobic and facultative anaerobic microorganisms (NMAfAnM) did not exceed values from 1.0×102 to 2.0×103 during 12 months of storage at a temperature of minus 21±1°C, which is significantly lower than the established maximum permissible value of 5.0×104 (technical regulation of the Customs Union 021/2011 ”On food safety” (TR CU 021/2011). All samples were free of Escherichia coli bacteria, mold showed growth of less than 10 colonies of forming units in 1 g with a standard of no more than 100 cells in 1 g (Tr CU 201/2011).

Analysis of the above data confirmed the possibility and feasibility of using dried laminaria grown on Frøyaisland (Norway) in the production of food products enriched with iodine. Due to its high iodine content and excellent safety indicators, dried laminaria can be classified as physiologically functional food ingredients.

Marketing research has revealed the groups of mass-consumption food products that are most in demand if they are enriched with iodine. These include popular flour products such as bread, as well as fermented milk products such as drinkable and thick yoghurts with fruit fillers.

The proposed technologies for the production of these products enriched with iodine contain all the stages of basic technologies. The only innovative step is the introduction of dried finely ground kelp in the composition of prescription sets of bread and fruit fillers for fermented milk products.

The optimal dosage of dried laminaria in the recipe of the new products is determined by calculation, based on the experimentally established iodine content in dried algae. Also, the calculation took into account the factor of ensuring the iodine content in 100 g of the finished product in an amount of at least 15 and no more than 50% of the recommended level of adequate iodine intake (from 150 to 250 micrograms per day) in accordance with the requirements of GOST R 52349 – 2005 ”Functional food products: terms and definitions”.

TABLE 1: Results of the study of the composition and safety of dried seaweed depending on the pretreatment and low-temperature drying modes

Heat pump drying at a temperature of minus 10 °C for different number of layers:
Heat pump drying at a temperature of minus 10 °C in one layer
Mass fractionwater, %6,60±0,50
Masspercentage of ash (mineral substances), % by total weight46,58±0,21 % in terms of drysubstance 47,61±0,23
Mass fraction of total nitrogen, % by total weight 1,71±0,17 % in terms of drysubstance 1,83±0,20
Mass fraction of protein, % by total weight 9,06±0,14
Mass fraction of iodine, % in terms of drysubstance 0,367±0,01
Mass fraction of sodium chloride, % in terms of drysubstance 31,00±1,75
Heat pump drying at a temperature of minus 10 °C in threelayer
Mass fractionwater, % 6,00±0,50
Masspercentage of ash (mineral substances), % by total weight 46,40±0,20 % in terms of drysubstance 49,36±0,25
Mass fraction of total nitrogen, % by total weight 2,00±0,17 % in terms of drysubstance 2,10±0,20
Mass fraction of protein, % by total weight 10,06±0,20
Mass fraction of iodine, % in terms of drysubstance 0,367±0,01
Mass fraction of sodium chloride, % in terms of drysubstance 31,00±1,75
Vacuum freeze drying of algae after pre-storage at a temperature from 8 to 2 °C for different storage times:
Vacuum freeze drying of algae after pre-storage at a temperature from 8 to 2 °C for 2 days of storage:
Mass fractionwater, % 6,89±0,35
Masspercentage of ash (mineral substances), % by total weight 50,14±0,50 % in terms of drysubstance 53,73±0,55
Mass fraction of total nitrogen, % by total weight 1,52±0,11 % in terms of drysubstance 1,56±0,12
Mass fraction of protein, % by total weight 8,07±0,15
Mass fraction of iodine, % in terms of drysubstance 0,472±0,01
Mass fraction of sodium chloride, % in terms of drysubstance 31,00±1,75
Vacuum freeze drying of algae after pre-storage at a temperature from 8 to 2 °C for 4 days of storage:
Mass fractionwater, % 6,91±0,20
Masspercentage of ash (mineral substances), % by total weight 47,71±0,45 % in terms of drysubstance 51,25±0,52
Mass fraction of total nitrogen, % by total weight 1,11±0,10 % in terms of drysubstance 1,12±0,10
Mass fraction of protein, % by total weight 5,88±0,18
Mass fraction of iodine, % in terms of drysubstance 0,472±0,01
Mass fraction of sodium chloride, % in terms of drysubstance 31,00±1,75
Vacuum freeze drying of algae after pre-freezing and storage at a temperature mines 25 °C for different storage times:
Vacuum freeze drying of algae after pre-freezing and storage at a temperature mines 25 °C for 2 days of storage:
Mass fractionwater, % 6,93±0,20
Masspercentage of ash (mineral substances), % by total weight 47,97±0,50 % in terms of drysubstance 51,55±0,63
Mass fraction of total nitrogen, % by total weight 2,33±0,18 % in terms of drysubstance 2,36±0,20
Mass fraction of protein, % by total weight 12,35±0,35
Mass fraction of iodine, % in terms of drysubstance 0,522±0,01
Mass fraction of sodium chloride, % in terms of drysubstance 31,00±1,75
Vacuum freeze drying of algae after pre-freezing and storage at a temperature mines 25 °C for 6 days of storage:
Mass fractionwater, % 7,36±0,20
Masspercentage of ash (mineral substances), % by total weight 49,14±0,28 % in terms of drysubstance 52,94±0,32
Mass fraction of total nitrogen, % by total weight 1,59±0,14 % in terms of drysubstance 1,63±0,15
Mass fraction of protein, % by total weight 8,40±0,16
Mass fraction of iodine, % in terms of drysubstance 0,522±0,01
Mass fraction of sodium chloride, % in terms of drysubstance 31,00±1,75

Figure 1: Samples of fermented milk products «Drinkable yogurt with Apple-carrot filling» and «Drinkable yogurt with Apple-ginger filling», presented at the extended degustation at the 6th International conference «Fishing in the Arctic: international challenges, practices, prospects», Murmansk, Russia, March 19, 2019.

Optimization of the formulation composition of products was performed using the fuzzy logic method in the MatLab software package (Fuzzy Logic block). The optimization parameter was the organoleptic evaluation of the product, and the influencing factors were the key components of the formulation that form this evaluation. The optimization criterion is to achieve the maximum organoleptic evaluation of the product.

Studies were conducted on the chemical composition of finished products made according to optimized recipes that provided the maximum organoleptic score (5 points on a five-point scale or a quality level of 100 % (Fig. 1).

The results for the product “Italian crisp breadsenriched withiodine” arepresentedinTable 2.Theresultsfor the fermented milk product – drinking yoghurts with fillers ”Apple-ginger” and ”Apple-carrot” are shown in table 3.

In all the studied yogurt samples, the number of live microorganisms at the end of the shelf life ranged from 1.0×1010 to 1.2×1010 colonies forming units in 1 g of the product, with a norm of at least 1×107. Based on the data obtained, developed products can be considered of a high quality, biological value and safety. The iodine content in products from 30 to 52.8% of the recommended consumption rate, allows to classify them as products enriched with iodine.

TABLE 2: Chemical composition and energy value of 100 g of the product «Italian crispbreads enriched with iodine».

Weightfraction %
Water 20,60
Totalnitrogen1,97
Non-protein nitrogen 0,42
Protein 9,70
Fat 20,40
Carbohydrates 47,50
Ash (the mineral matter) 1,80
Iodine, mkg per 100 g product 45 or 30 % of the recommended consumption rate
Energy value 100 g, Kcal 412.4
Titrated alkalinity, Turner degrees6,4
Wetability, % 121

TABLE 3: Chemical composition and energy value of 100 g of the fermented milk products enrichedwithiodine

Weightfraction %
Drymatter drinkable yogurt with filling «Apple-ginger» 15,77 drinkable yogurt with filling «Apple-carrot» 15,42 thick yogurt with filling «Carrotsstewed with vanilla» 19,33 thick yogurt with filling «Pumpkin stewed with nutmeg»18,54
Fat drinkable yogurt with filling «Apple-ginger» 2,5 drinkable yogurt with filling «Apple-carrot» 2,5 thick yogurt with filling «Carrots stewed with vanilla» 2,4 thick yogurt with filling «Pumpkin stewed with nutmeg» 2,4
Water drinkable yogurt with filling «Apple-ginger» 84,23 drinkable yogurt with filling «Apple-carrot» 84,61 thick yogurt with filling «Carrots stewed with vanilla»80,67 thick yogurt with filling «Pumpkin stewed with nutmeg» 81,46
Total nitrogen drinkable yogurt with filling «Apple-ginger» 0,34 drinkable yogurt with filling «Apple-carrot» 0,32 thick yogurt with filling «Carrotsstewed with vanilla» 0,34 thick yogurt with filling «Pumpkin stewed with nutmeg» 0,35
Protein drinkable yogurt with filling «Apple-ginger» 2,16 drinkable yogurt with filling «Apple-carrot» 2,04 thick yogurt with filling «Carrots stewed with vanilla» 2,13 thick yogurt with filling «Pumpkin stewed with nutmeg» 2,19
Carbohydrates drinkable yogurt with filling «Apple-ginger» 9,97 drinkable yogurt with filling «Apple-carrot» 9,98 thick yogurt with filling «Carrots stewed with vanilla» 13,60 thick yogurt with filling «Pumpkin stewed with nutmeg» 20,37
Dry skimmed milk residue (DSMR) drinkable yogurt with filling «Apple-ginger» 9,27 drinkable yogurt with filling «Apple-carrot» 8,92 thick yogurt with filling «Carrots stewed with vanilla» 16,93 thick yogurt with filling «Pumpkin stewed with nutmeg» 16,17
Iodine, mkg per 100 g product / % of the recommended consumption rate drinkable yogurt with filling «Apple-ginger» 66,0 / 44,0 drinkable yogurt with filling «Apple-carrot» 66,0 / 44,0 thick yogurt with filling «Carrots stewed with vanilla» 88 /35,2 thick yogurt with filling «Pumpkin stewed with nutmeg» 132 / 52,8
Energyvalue 100 g, Kcal drinkable yogurt with filling «Apple-ginger» 71 drinkable yogurt with filling «Apple-carrot» 71 thick yogurt with filling «Carrots stewed with vanilla» 85 thick yogurt with filling «Pumpkin stewed with nutmeg» 82
Titratable acidity, Turner degrees drinkable yogurt with filling «Apple-ginger» 85 drinkable yogurt with filling «Apple-carrot» 86 thick yogurt with filling «Carrots stewed with vanilla» 88 thick yogurt with filling «Pumpkin stewed with nutmeg» 89

4. Discussion

Analysis of the data presented in table 1 shows that the method of pretreatment and low-temperature drying of laminaria, as well as the mode of subsequent storage of algae in a polymer package without vacuum, affects individual functional and technological properties. Thus, the mass fraction of moisture and dry matter, as well as the mass fraction of sodium chloride in dried laminaria is almost the same in all processing options. The content of components that characterize the nutritional and biological value of dried laminaria – protein and iodine – depends on the method of pre-treatment and drying. Obviously, this is due to the peculiarities of the formation of the preserving effect in laminaria under the influence of physical factors, as well as the depth of biochemical changes in the drying process.Protein is most preserved in laminaria frozen at a temperature of minus 25 °C before freeze-drying, followed by storage at the same temperature: the value of the indicator fluctuates about 11% with a tendency to gradually decrease during storage. The lowest protein content is observed in laminaria subjected to freeze-drying after freezing to a temperature of minus 8 °C, followed by storage at the same temperature. As is known, at this temperature, the maximum denaturation and hydrolysis of proteins under the action of proteolytic enzymes is observed. This shows a decrease in protein content to 9-5 % in experimental samples of dried laminaria. In the case of drying with use of a heat pump without pre-storage, the protein is stored at a level of about 10%, while drying the algae in one layer preserves the protein to a lesser extent compared to drying in three layers. Table 1 shows that the mass fraction of iodine differs for different drying methods and pre-treatment modes. Thus, reducing the storage temperature to freeze-drying from minus 8 to minus 25 °C provides an increase in the iodine content by about 10% – from 0.472 to 0.522%. The transition from heat pump drying to freeze drying gives an increase in the indicator by an amount from 29 to 42% – from 0.367 to 0.472 and0.522 %. Thus, the research made it possible to reasonably recommend pre-storage of laminaria in the collection areas in frozen form at a temperature of minus 25 °C for up to 6 days, followed by freeze-drying. This technological algorithm will most ensure the preservation of the nutritional value and functional and technological properties of the algae among the considered processing options.

The data in tables 2 and 3 show the high nutritional and biological value of the developed products. Due to the introduction of dried laminaria products into the formulation, the content of iodine in them has been achieved, providing from 30 to 53 % of the recommended level of adequate consumption. Thus, it is possible to make unambiguous conclusion about the functional properties of new products of mass consumption.

5. Conclusion

For the first time,the influence of various methods of pretreatment and low-temperature drying (heat pump and vacuum freeze drying) on the functional and technological properties of the mariculture object Laminaria Saccharina algae was studied. The high content of iodine has been experimentally proved, and the preservation of excellent quality and safety of dried algae during storage in a polymer package without vacuum at a temperature of minus 21±1°C for 12 months has been confirmed. The expediency of using laminaria dried by cold drying, in the technology of manufacturing food products enriched with iodine is justified.

Optimal recipes have been developed and technologies have been proposed for the production of food products enriched with iodine and intended for mass consumption: ”Italian crispbreadsenriched with iodine”, drinkable yoghurts with fruit fillers ”Apple-ginger” and ”Apple-carrot”, as well as thick yoghurts with fillers ”Carrot stewed with vanilla” and ”Pumpkin stewed with nutmeg”. Due to the use of dried seaweed Laminaria Saccharina as an enriching additive, a high content of iodine is achieved in new products. Thus, the study is aimed at solving a socially significant problem of prevention of thyroid diseases in the population of the Russian Federation and Norway.

6. Funding

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7. Conflict of Interest

The authors have no conflict of interest to declare.

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