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DEVELOPMENT OF THE TECHNOLOGY OF SOYA FLOUR ENRICHED WITH IODINE

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Abstract. A research on developing a technology of iodine-enriched soya flour has been conducted. The technology developed will allow the body to receive organic forms of this micronutrient, the deficiency in which causes thyroid disorders in 40% of Ukrainians and 35% of people throughout Europe. The research has shown that promising soya bean varieties to be enriched with iodine are the early-ripening varieties *Almaz, Anzhelika, Kyivska 98, Faeton, Medeya, PSV 808, Podyaka, Khortytsya, Yug 30, Rusa.* They are the highest in protein (42.75% on average), the maximum content of which is necessary for iodine accumulation. Besides, their cropping period is short (up to 95–105 days), which is cost-effective for a manufacturing enterprise, because there is no overlapping with the winter crops sowing time and thus, there are no periods when cultivation areas remain idle. The following parameters of steeping soya beans have been found rational: the iodine concentration in the solution 98–100 μg/g, the duration of steeping 48 hours. The mass fraction of iodine in the steeped soya beans is 126 μg/g. Longer steeping leads to microbiological spoilage of sprouted soya beans. It has been determined how iodine is distributed in cotyledons, sprouts, seed coats, and whole sprouted soya beans. This has allowed establishing that in a whole sprouted soya bean of the early-ripening soya variety *Almaz*, the iodine content is 126 μg/g, of which 123 μg/g is accumulated in the cotyledons of a seed, and 3 μg/g in the sprouts and the seed coats. This indicates a high level of iodine conversion into the organic form when soya seeds are steeped in potassium iodide solution. A technology of manufacturing iodine-enriched flour from sprouted soya beans has been developed. It differs from the control one in that soya seeds, washed and disinfected, are soaked in potassium iodide solution (with the iodine concentration 98–100 μg/g and the hydromodulus 1:2) for 48 hours at the solution temperature 14–16°C. Flour from sprouted soya beans contains 126 μg/g of iodine. The technology suggested can be used at hotel and catering enterprises, in sanatoria and health centres, to treat iodine-deficiency disorders, and to make food for people who need special dietetic nutrition.

Keywords: special dietetic nutrition products, flour, soya bean, iodine, sprouted seeds.

Introduction. Formulation of the problem

Creation of synthetic and chemically modified products, lower proportion of natural products in people's diet, psychological and emotional stress, and environmental deterioration have led to a sharp increase of morbidity rates [1]. To increase the human body's resistance, it is necessary to create dietary and health-improving foods and rations [2]. Special attention should be paid to deficiency in micronutrients: they are the most important catalysts of biochemical processes and take part in the synthesis and metabolism of hormones. In particular, this refers to iodine, lack of which may lead to thyroid pathologies. Almost 40% of Ukrainians and 35% of people throughout Europe suffer from thyroid disorders [3]. According to WHO and UNICEF experts, more than one billion people on the Earth are at risk of developing iodine-deficiency diseases. This was the reason why activities aimed at preventing and controlling iodine-deficit diseases were included in the priority international programmes [4]. The ingredient most commonly used in cooking by the Slavic peoples is flour. This ingredient is highly demanded by consumers as it can be used to make bakery products, meat and fish dishes. Flour obtained from wheat, rye, barley contains gluten. This substance contributes to development of atrophy of the mucous membrane of the small intestine in gluten-intolerant people. In Ukraine, there are about 400 thousand people with this disease. According to the requirements of the WHO's Codex Alimentarius, gluten-free products for special dietary nutrition are those containing no more than 20 μg/g of gluten [5].

We consider that, when developing an enriched flour technology, it is rational to use gluten-free raw materials high in vegetable protein. In our opinion, it can be done in the course of steeping when soya seeds are sprouting. Pulses are known to be capable of accumulating micronutrients when steeped in the process of sprouting, and the mass fraction of enriching micronutrients depends on the protein contents in the native seed [6-8]. The previous studies have shown that the best iodine accumulator is a soya seed [9,10]. To develop a technology of obtaining flour from sprouted soya beans enriched with micronutrients in the metabolised form, it is necessary to transport into the seeds as much of the micronutrient as possible. This can be achieved by using solutions of mineral salts, potassium iodide (PI), which is a carrier of the maximum iodine quantity, 0.76 μg in 1 g of the substance. Today, development of new technologies for special dietetic rations, which can be introduced at hotel and catering enterprises, in sanatoria and health centres, is an important social task.

Analysis of recent research and publications

75 countries in the world have programmes of compulsory micronutrient enrichment of wheat flour [11]. Pulse flour is fortified (enriched) in almost one third of the countries of the world [12]. The US Food and Drug Administration (FDA) introduced compulsory fortification of pulse flour. The countries that next started enriching flour were Canada and Chile. Today, the number of countries that have taken this course is rapidly growing [13].

In 2014–2019, in the Rivne, Khmelnytsky, and Volyn regions of Ukraine, 2399 patients with endemic goitre were registered. Medical scientists attribute this to lack of iodine [14]. A standard requirement of iodine is 150 μg per 24 hours [15]. On 14 January 2013, the Ministry of Health Care of Ukraine issued order No. 15. It approved the Methodical Recommendations for general practitioners and family therapists about consulting their patients on the main principles of healthy nutrition. The document stated iodine as a vitally important micronutrient to prevent and cure endocrine and hormonal diseases. Sufficient intake of the micronutrient is necessary to prevent intellectual disability in premature infants, infertility, physical and intellectual developmental defects, deaf-mutism, neurological cretinism, eyesight degradation, and such diseases as nodular goitre and thyroid cancer [16]. To replenish the human body with micronutrients, they can be supplied in two forms: mineral (not bound to an organic molecule) and organic (chemically bound to any organic compound, like sugar or amino acid) [17]. It is vital to use organic carriers of iodine when consuming food. They are more heat-resistant and do not react with chemical compounds within the body, so do not change or destroy them. Thus, there is no possibility of overdosing and intoxication.

Members of the Ukrainian Parliament (Verkhovna Rada) intend to oblige flour producers to add vitamins and minerals into their products. This is what is said in bill No. 9117 registered in the Rada [18].

There are scientific works on developing a technology of enriching soya flour with iodine [19], which involves germinating soya seeds of the variety *Kyivska 98* in aqueous extract of kelp, their hydromechanical processing, grinding them into particles as small as 280-850 μg, and drying. The method suggested allows receiving a product with high consumer properties and increased nutritional value. However, the researches only studied the above mentioned variety, which does not allow determining the most promising pulse varieties to be enriched with micronutrients. Neither was the iodine content quantified exactly, only the range of values was determined.

There is another method of enriching soya flour [20]. By this method, at the first stage of making a saline solution, edible sea salt is dissolved in distilled water (t=22–24°C) in the proportion 2:98. The 2% solution obtained is used for soya bean sprouting. At the second stage, the soya beans are sorted, washed, put into a container, covered with the saline solution, and left to germinate in a dark place at 20–24°C until sprouts are formed as long as 1–2 mm. The sprouted soya beans are placed on sieves and dried at 65–70°C in the oven for 12–14 hours until the moisture content is 14%. The dried soya beans are milled into flour and sifted through a 1-mm sieve. According to the study, flour produced by this technology is higher in macro- and micronutrients than the control sample. However, the researchers did not establish how the chemical composition of seeds, namely their protein content, affected the level of micronutrient accumulation.

All these technological approaches their inventors use to develop technologies of iodine-enriched soya flour have a number of drawbacks: micronutrients are quantified approximately; only one variety is studied; the content of nutrients in the enriched seed is not determined, the distribution of iodine is not considered (not determined which part of a seed accumulates the maximum of iodine).

Since there are no data on how the mass fraction of iodine in the steeped seeds with different protein contents depends on the iodine concentration in the solution and on the duration of sprouting, and there is no information about how iodine is distributed in different parts of sprouted seeds, deeper and more extensive studies in this direction are needed.

Purpose and objectives of the study. The purpose of the study is developing a technology of obtaining soya flour enriched with iodine. To achieve the purpose, the following objectives were set:

– to optimise the contents of nutrients in soya seeds of various vegetation varieties and identify which varieties are promising to be enriched;

– to study how the iodine mass fraction in steeped soya seeds with different protein contents depends on the concentration of iodine in the solution and the duration of sprouting;

– to determine the distribution of iodine in cotyledons, sprouts, seed coats, and in whole sprouted seeds;

– to develop a technological scheme of manufacturing iodine-containing flour.

Research materials and methods

In the research, the following soya varieties were used: the ultra-early ripening varieties *Adamos*, *Anastasia*, *Annushka*, *Aleksandrit*, *Bilyavka*, *Vilshanka*, *Vorskla*, *Deni*, *Elena*, *Feya* (ripening period 75–85 days); the early-ripening varieties *Almaz*, *Anzhelika*, *Kyivska 98*, *Faeton*, *Medeya*, *PSV 808*, *Podyaka*, *Khortytsya*, *Yug 30*, *Rusa* (ripening period 95–105 days); the medium-early ripening varieties *Artemida*, *Delta*, *Ivanka*, *Tavria*, *Zolotysta*, *Sprynt*, *Kharkivska*, *Sharm*, *Yug 40* (ripening period 100–115 days); the mid-ripening varieties *Agat*, *Vityaz 50*, *Kolbi*, *Poltava*, *Sribna*, *Uspikh*, *Masha*, *Deymos*, *Anna*, *Podillya* (ripening period 115–125 days). The characteristics of the solutions are presented in Table 1.

Table 1 – Characteristics of the solutions

No.	Iodine content in the solutions (1 g of PI is a carrier of 0.76 μg/g of iodine)			
1	Amount of iodine, μg	20	50	100
2	Amount of PI, g	15.2	38.0	76.5

Methods of research. The contents of nutrients in the sprouted seeds were studied by ion-exchange and liquid chromatography using a liquid chromatograph Shimadzu LC-20. Mathematical optimisation was carried out by means of the programme MATLAB. The mathematical model is based on all the data on varieties of different vegetation periods within five years, and 400 indicators have been mathematically processed. The criteria to estimate the varieties most promising to enrich were: maximum amount of protein, minimum ripening period, average content of fats and carbohydrates.

The method of steeping the seeds is described in [21]. To assess the organoleptic characteristics of the sprouted seeds, a five-point scale was used: 1 – very bad, 90% of seeds are dark-coloured, rotten, and unusable; 2 – ≤70% of seeds are spoilt, dark-coloured, rotten; 3 – ≤30% of seeds are spoilt, dark-coloured, rotten; 4 – ≥10% of seeds are spoilt, dark-coloured, rotten; 5 – no spoilt, dark-coloured, rotten seeds (usable).

The mass fraction of iodine was determined with a voltammetric analyser Ekotest-VA equipped with a silver-impregnated graphite electrode, an auxiliary electrode, a reference electrode. The iodine identification method is based on electrochemical oxidation of iodine ions to molecular iodine, precipitation of the iodine-containing poorly soluble complex compound, and further electrochemical dissolution of the precipitate on the surface of the working electrode with linear potential sweep. By measuring the cathodic current when dissolving the precipitate, the mass concentration of iodine in the solution under study is calculated.

The localisation of iodine distribution in a whole seed, in its cotyledons, sprouts, and coats has been established in seeds of the variety *Almaz* (with the total content of protein in the seeds before steeping 43.88%) steeped for 48 hours. In the PI solution (76.5 g per 100 cm^3), the predicted concentration of iodine was 100 μg.

While developing the technology, the control technological scheme was the one used to produce flour from sprouted soya bean [22].

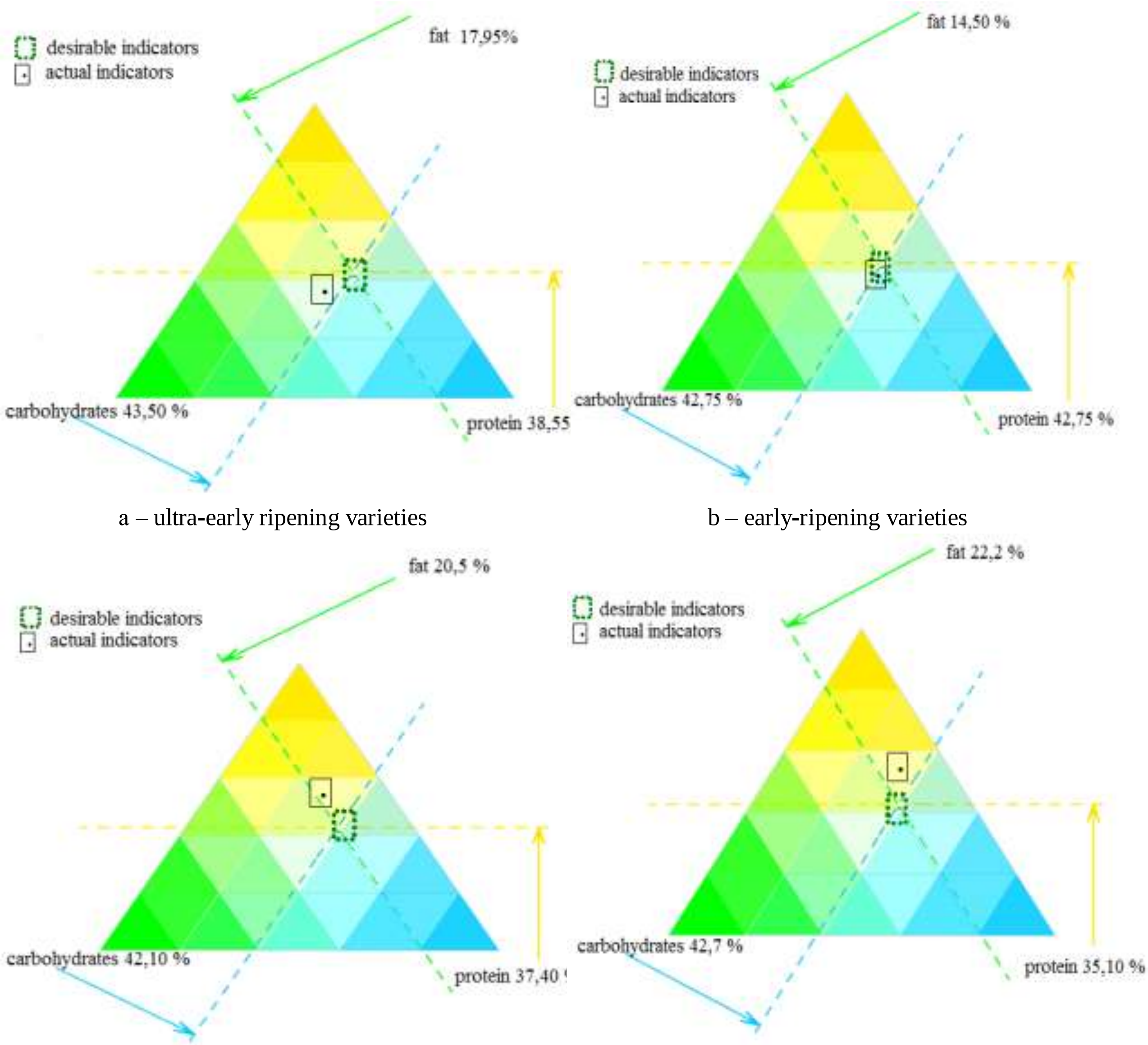
Results of the research and their discussion

Fig. 1 presents the characteristics of the samples of soya seeds used in the research and taken from the collection breeding centre *Agrotek* in 2014–2018.

From the data in Fig. 1 (a, b, c, d), it has been found that soya seeds of different vegetation varieties differ quite considerably in their content of proteins, fats, and carbohydrates. This is due to different periods of ripening and to climatic factors (the number of hot and rainy days) that tell considerably on the chemical composition of pulses.

The best result can be found in the samples of early-ripening soya varieties (Fig. 1b). They are maximally close to the desired values of the maximum protein amount and minimum cultivation period. Their content of protein is 42.75%, of fat 14.50%, of carbohydrates 42.75%, and the vegetation period of their growth is up to 95–105 days. Cultivating early-ripening soya varieties is cost-effective for a manufacturing enterprise, because there is no overlapping with the winter crops sowing time and thus, there are no periods when cultivation areas remain idle.

Compared to early-ripening soya varieties, the protein content in ultra-early ripening varieties is lower by 4.2%. In medium-early ripening and mid-ripening varieties, it is lower by 5.35 and 7.65%, respectively (Fig. 1a, c, d). This makes them far less promising as raw materials for enriched flour.



a – ultra-early ripening varieties b – early-ripening varieties

c – medium-early ripening varieties d – mid-ripening varieties

Fig. 1. Optimisation of nutrients in soya seeds of different vegetation periods and different varieties, from the collection breeding centre *Agrotek* in 2014–2018
(a – ultra-early ripening varieties, b – early-ripening varieties, c – medium-early ripening varieties, d – mid-ripening varieties)

Mid-ripening soya varieties are by 1.7% and 0.6% higher in fat and carbohydrates (respectively) than medium-early ripening varieties. Soya beans of mid-ripening varieties ripen by 10–15 days faster than those of medium-early ripening varieties.

On analysing the data, it has been found that the most promising for iodine enrichment are the early-ripening soya varieties *Almaz*, *Anzhelika*, *Kyivska 98*, *Faeton*, *Medeya*, *PSV 808*, *Podyaka*, *Khortytsya*, *Yug 30*, *Rusa*.

Table 2 shows how the iodine mass fraction in the steeped soya seeds with different protein content depends on the iodine concentration in the solution and on the sprouting period.

The content of the iodine mass fraction has been determined using soya varieties with different protein contents, which, by our hypothesis, can influence the content of the micronutrient accumulated by a seed. The concentration of the micronutrient in the solution for germination was based on the Ministry of Health Care's Order No. 1037 "On adoption of standards of Ukrainian people's physiological needs for basic nutrients and energy" (03.09.2017). Besides, the nutritiological principles were taken into account concerning the content of physiological functional ingredients in fortified products (according to these principles, consuming 100 g of the product developed must satisfy 25–30% of the daily requirement).

Table 2 – Iodine mass fraction in soya seeds with different protein content and its dependence on the iodine concentration in the solution and on the sprouting period

No	Soya variety	Protein content, %	Iodine concentration, µg/g				
			0	20	50	100	Sensory characteristics, point $X^1/X^2/X^3$*
Iodine content in the sprouted seeds in 12 hours after steeping, µg/g							
1	Adamos	41.20	-	12	36	71	5/5/5
2	Almaz	43.88	traces	19	45	92	5/5/5
3	Kolbi	36.58	-	9	26	53	5/5/5
4	Kharkivyanka	37.21	-	10	31	68	5/5/5
Iodine content in the sprouted seeds in 24 hours after steeping, µg/g							
1	Adamos	41.20	-	15	46	89	5/5/5
2	Almaz	43.88	traces	22	52	106	5/5/5
3	Kolbi	36.58	-	11	39	65	5/5/5
4	Kharkivyanka	37.21	-	13	44	78	5/5/5
Iodine content in the sprouted seeds in 48 hours after steeping, µg/g							
1	Adamos	41.20	-	16	48	95	5/5/5
2	Almaz	43.88	traces	23	54	126	5/5/5
3	Kolbi	36.58	-	12	41	74	5/5/5
4	Kharkivyanka	37.21	-	15	45	82	5/5/5
Iodine content in sprouted seeds in 72 hours after steeping, µg/g							
1	Adamos	41.20	-	19	52	103	4/2/2
2	Almaz	43.88	traces	28	67	144	4/3/2
3	Kolbi	36.58	-	13	43	82	4/2/1
4	Kharkivyanka	37.21	-	14	48	95	4/3/1

*__Note:__ sensory characteristics after: X^1 – 12 hours of steeping; X^2 – 24 hours of steeping; X^3 – 48 hours of steeping.

It has been established that if soya seeds are steeped for more than 48 hours, the sensory characteristics of steeped soya beans in the samples with the iodine concentration in the solution 100 µg/g deteriorate considerably: the beans spoil and become inedible.

Fig. 2 shows how the organoleptic characteristics of soya seeds change with different iodine concentrations in the solution and different sprouting periods.

Analysis of the experimental data allows establishing, as rational, the following parameters of the process of steeping soya beans: iodine concentration in the solution 20-100 µg/g, duration of steeping 48 hours (Table 2). The iodine mass fraction in a steeped soya seed varies from 71 to 126 µg/g. Longer steeping leads to microbiological spoilage of the sprouted seeds (Fig. 2).

The main characteristic of the effectiveness of the enriched flour technology is iodine accumulation in the metabolised protein fraction of seeds, as it is known that organic compounds of micronutrients, unlike inorganic, have the highest bioavailability and level of retention in the human body.

Table 3 illustrates the iodine distribution by anatomic parts of a sprouted soya seed.

On determining the iodine distribution in the cotyledons, sprouts, seed coats, and sprouted seeds in the whole, it has been established that a sprouted seed of the early-ripening soya variety *Almaz* contains a total of 126 µg/g of iodine: 123 µg/g of iodine is accumulated in the cotyledons, and 3 µg/g in the sprouts and seed coats. This indicates a high level of iodine conversion into the organic form in the course of steeping soya seeds in PI solutions.

The experimental results obtained and the parameters established in the previous studies [9,10,21] have become the basis for the development of a technological scheme of manufacturing iodine-containing soya flour. The process chart is shown in Fig. 3.

a b c d

Fig. 2. Changes in the organoleptic characteristics of soya seeds caused by different iodine concentrations in the solution and different sprouting periods: a – soaking period 12 hours, iodine concentration in the solution 100 µg/g; b – soaking period 24 hours, iodine concentration in the solution 100 µg/g; c – soaking period 42 hours, iodine concentration in the solution 100 µg/g; d – soaking period 72 hours, iodine concentration in the solution 100 µg/g.

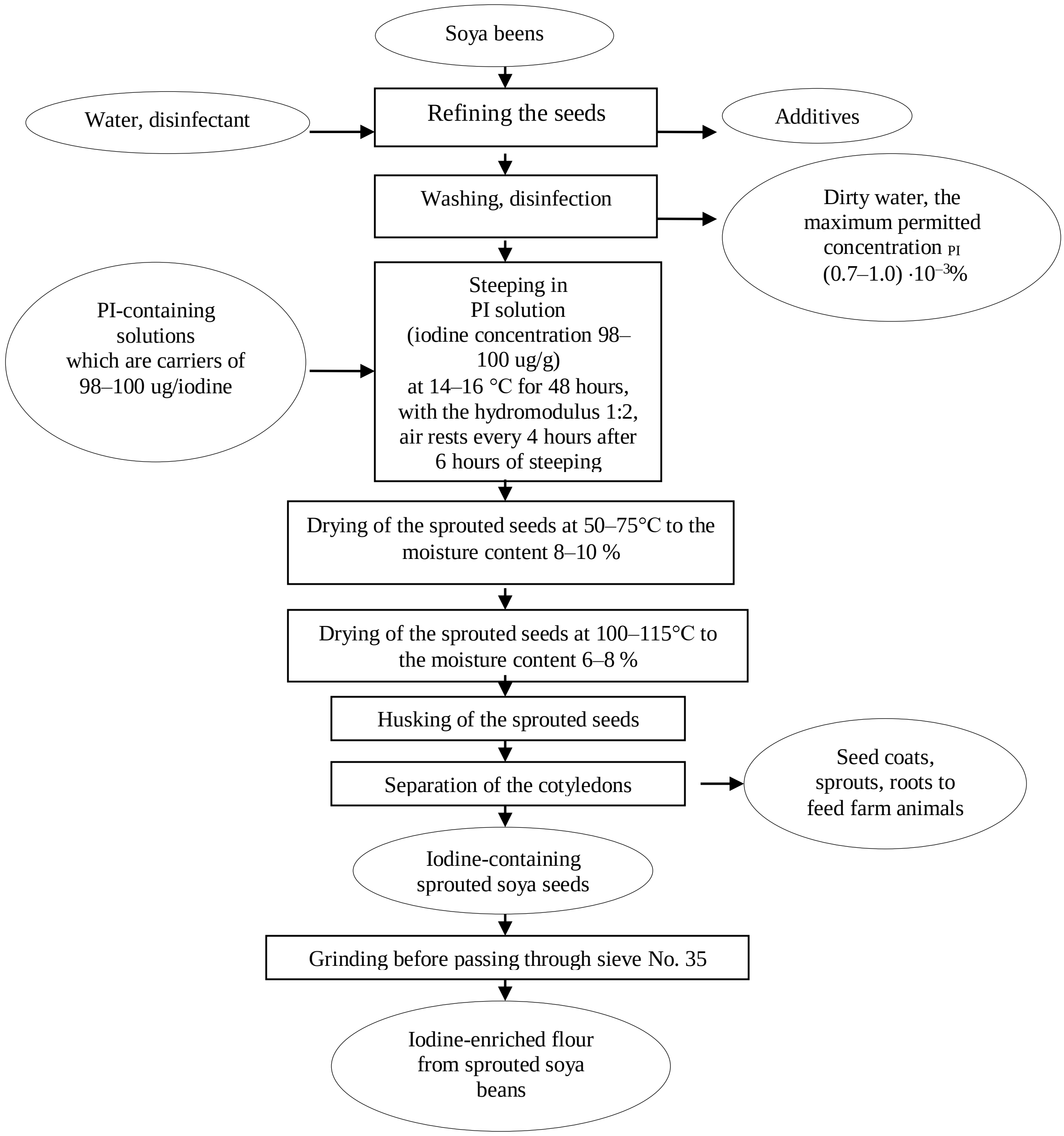


Fig. 3. Process chart of obtaining iodine-enriched flour from sprouted soya beans

Table 3 – Iodine distribution by anatomic parts of a sprouted soya seed of the early-ripening variety *Almaz*

No.	Anatomic part of a sprouted soya seed	Iodine content, μg/g
1	Cotyledons	123±0.3
2	Sprouts and seed coats	3±0.2
3	Sprouted seed (in the whole)	126±0.2

The technological scheme of obtaining iodine-enriched flour from sprouted soya beans does not require supplementary equipment. It differs from the control method in how solutions for steeping are prepared. The preparation consists in steeping soya seeds in potassium iodide solution with the iodine concentration 98-100 μg/g and the hydromodulus 1:2 for 48 hours at the temperature of the solution 14–16°C. This technology provides the iodine content in the flour 126 μg/g. As in recent years, there has been appearing more and more private hotel and catering enterprises which produce convenience food of a high level of readiness, the technology we suggest can find its application at these enterprises.

Approbation of results

The research was conducted in co-operation with the private enterprise *Agrotek* that provided the materials and the technical facilities. The technology developed by us has been integrated into the production process at the private enterprise *Agrotek* (certificate of producing an experimental batch 09.09.2019.). The technical specifications have been approved (TU U 10.6-02071205-001:2019, safety and health certificate No.12.2-18-2/20401 "Soya flour enriched with iodine." The flour developed is used as an ingredient to produce gluten-free bread for special dietetic nutrition in the diet of patients in the sanatorium *Borysfen* (Ochakiv, Mykolaiv Region, Ukraine) and in the Ukrainian cuisine café *Kobzar* (Kharkiv, Ukraine).

Conclusion

The promising soya varieties for enrichment with iodine are the early-ripening varieties *Almaz*, *Anzhelika*, *Kyivska 98*, *Faeton*, *Medeya*, *PSV 808*, *Podyaka*, *Khortytsya*, *Yug 30*, *Rusa*. They are the highest in protein (42.75% on average), the maximum content of which is necessary for iodine accumulation. Besides, their cropping period is short (up to 95–105 days), which is cost-effective for a manufacturing enterprise, because there is no overlapping with the winter crops sowing time and thus, there are no periods when cultivation areas remain idle.

The following parameters of soya bean steeping have been found rational: the iodine concentration in the solution 98–100 μg/g, the duration of steeping 48 hours. The mass fraction of iodine in the steeped soya beans is 126 μg/g. Longer steeping leads to microbiological spoilage of sprouted soya beans.

On determining the iodine distribution in the cotyledons, sprouts, seed coats, and sprouted seeds in the whole, it has been established that a sprouted seed of the early-ripening soya variety *Almaz* contains a total of 126 μg/g of iodine: 123 μg/g of iodine is accumulated in the cotyledons, and 3 μg/g in the sprouts and seed coats. This indicates a high level of iodine conversion into the organic form in the course of steeping soya seeds in PI solutions.

A technology of manufacturing iodine-enriched flour from sprouted soya beans has been developed. It differs from the control one in that soya seeds, washed and disinfected, are soaked in potassium iodide solution (with the iodine concentration 98–100 μg/g and the hydromodulus 1:2) for 48 hours at the solution temperature (14–16)°C. Flour from sprouted soya beans contains 126 μg/g of iodine. The technology suggested can be used at hotel and catering enterprises, in sanatoria and health centres, to treat iodine-deficiency disorders, and to make food for people who need special dietetic nutrition.

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РОЗРОБКА ТЕХНОЛОГІЇ БОРОШНА СОЇ ЗБАГАЧЕНОГО ЙОДОМ

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Анотація. Проведено дослідження по розробці технології борошна сої збагаченого йодом. Розроблена технологія дасть змогу надходження органічних форм мікроелементу дефіцит якого призводить до захворювання щитоподібної залози, якими страждають майже 40% населення України та 35% населення Європи. У результаті дослідження встановлено, що перспективними сортами сої для збагачення на йод є ранньостиглих сорти, а саме: «Алмаз», «Анжеліка», «Київська 98», «Фаетон», «Медея», «ПСВ 808», «Подяка», «Хортиця», «Юг 30», «Руса». Вони мають найбільший вміст білка – 42.75% (середнє значення), максимальний вміст якого необхідний для акумуляції йоду та не довгий період вирощування до 95–105 діб, що є економічно вигідною для «підприємства-виробника» бо не накладається на посівні озими, як наслідок, до простоювання посівних площ. Встановлено, що раціональні параметри процесу замочування сої, за якими концентрація йоду у розчині повинна сягати 98–100 мкг/г при тривалості замочування 48 годин. Вміст масової частки йоду у замоченому зерні сої становить 126 мкг/г. Збільшення часу замочування призводить до мікробіологічного псуванню пророслого зерна. Визначивши розподіл йоду у сім’ядолях, паростках і оболонках та пророслому зерні в цілому, встановлено, що у складі пророслого зерна раньостиглого сорту сої «Алмаз», вміст йоду у цілому зерні становить 126 мкг/г, із яких 123 мгк/г йоду акумульовано у сім’ядолях зерна, а 3 мкг/г йоду акумулюються у паростках та оболонках, що свідчить про високий ступінь конверсії йоду в органічну форму під час замочування зерен сої у розчинах KI. Розроблена технологічна схема виробництва борошна пророщеної сої збагаченої йодом, яка відрізняється від контрольної тим, що після миття та дезінфекції, зерна сої замочують у розчині йодиду калію із концентрацією йоду 98–100 мкг/г, при гідромодулі 1:2 на протязі 48 годин при температурі розчину від 14°С до 16°С. Борошно пророщених зерен сої є носієм 126 мгк/г йоду. Запропонована технологія може бути використана на підприємствах готельно-ресторанного господарства, санаторіях профілакторіях, для осіб із йод дефіцитними станами та для задоволення вимог споживачів із спеціальним дієтичним харчуванням.

Ключові слова: вироби спеціального дієтичного споживання, борошно, соя, йод, пророщені зерна.

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