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Development of technology for the production of Dutch waffles (stroopwaffels) from using domestic soybean flour

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ABSTRACT

Background: Cultivation of crops by hydroponic method helps to increase the yield and nutrition of plants while avoiding the use of pesticides. The cultivation of crops with this method is especially necessary in those countries where the soil or climate is not favorable for the cultivation of similar crops, such as the Republic of Armenia. Soybeans are a great source of protein, dietary fiber, and biologically active substances.

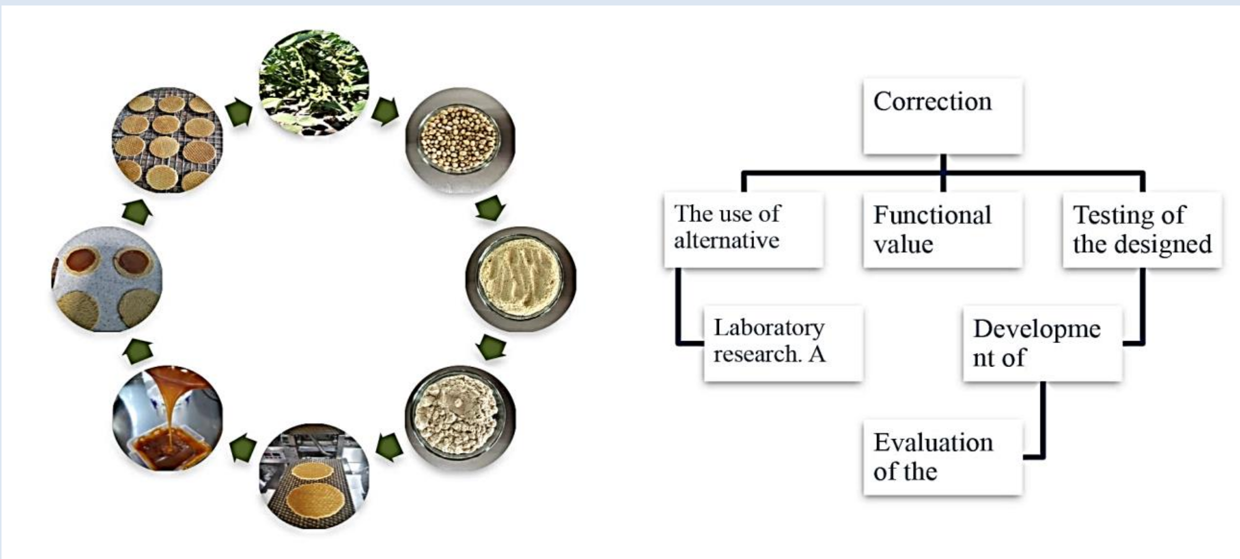
Objective: The aim of the study is to obtain flour from domestic soybeans grown using the hydroponic method and use it in confectionery products as a functional additive.

Methods: In food analysis, the concept of "protein" often refers to the amount of total nitrogen determined by the Kjeldahl method. The method consists of 3 stages: Dissolution, Steam distillation, titration. In addition, the study used modern methods for determining humidity, wettability, amino acid composition with the using of new equipment.

Results: When developing the waffle recipe, the primary task was to avoid using any alternative improvers typically used to ensure quality and stability. The technological parameters have been developed according to this principle, so that a high-quality product can be obtained without using food additives that are typically used to obtain traditional products.

Conclusion: The article evaluates the amino acid composition of hydroponically and locally produced soybean flour, which was compared with the amino acid composition of other raw materials used in confectionery. The scientific and experimental results can be implemented in the domestic production market, contributing to the food chain in three directions of development: hydroponic soybean cultivation, new device production, and the release of a new type of waffle product. Thus, our studies have important industrial significance and can be used as favorable means for the development of souvenir production.

Key words: Whole grain soy flour, waffles, essential amino acids, waffle maker



Graphical Abstract: The technological chain of production of Dutch waffles and background for the research

INTRODUCTION

Functional foods are healthy foods that have a balanced nutritional composition. Functional foods are most often chosen because they contain components with immunomodulatory, antioxidant, anti-inflammatory, anti-toxic, or other properties [1-2] .

However, a standard definition of functional nutrition does not yet exist, leading to confusion among consumers, developers, and the government. The Functional Food Center (FFC) currently defines functional foods as "natural or processed foods that contain biologically active compounds; which, in defined, effective, non-toxic amounts, provide a clinically proven and documented health benefit utilizing specific biomarkers, to promote optimal health and reduce the risk of chronic/viral diseases and manage their symptoms'' [3].

Bioactive food compounds affect the function of the body's organs and systems. These ingredients control cellular metabolism and create stable homeostasis at different periods of life [4]. These bioactive food compounds are studied for their positive effect on health beyond basic nutrition, as well as testing their security, potency, and quantifiable effects. Functional food science has a legitimate role to play in integrative medicine, and it will only grow in relevance as the world seeks preventative options that will keep people healthy [5]. An important question when defining a functional food with respect to the FBCs is whether they propose a risk from a safety perspective. Among consumers is the perception that since these are natural products, they do not carry real associated risks. In fact, evidence exists regarding the risk of consuming an excess number of healthy substances such as antioxidants, omega 3, and soy isoflavones [5-6].

In the face of population growth, which is expected to reach nearly 10 billion by 2050, and the growing global demand for food (and meat), food insecurity is emerging as a global societal challenge The global market, which includes the production, distribution, and consumption of proteins produced for human consumption from various sources, is known as the "dietary protein market". Proteins are essential macronutrients that are vital for the development, maintenance, and repair of body tissues. In the food industry, proteins are imported from various sources to meet the nutritional needs of a healthy and densely populated world [6].

Plant-based protein substitutes such as soy, mycoprotein, and legumes are gaining popularity due to environmental concerns [6]. Soy remains the richest food with perfect protein amino acid composition and high protein content.

Crop cultivation by hydroponic methods helps increase yield and nutrition, avoiding the use of pesticides [7].

The cultivation of crops with this method is essential in countries where the soil or climate is not favorable for the cultivation of similar crops, such as the Republic of Armenia [8].

Protein deficiency is a serious problem for agricultural sustainability and the food industry. The continued lack of systematic attention to legumes threatens food security, human health, and sustainable food production. Soybeans have the highest protein content among other legumes, and soy protein’s quality is close to that of animal protein. Soybeans are a vital source of healthy fats such as omega-3 and 6 fatty acids [9-11].

Flour confectionery is a high-calorie and low-biological food. It contains almost no useful components, including protein. It is important to use non-traditional raw materials containing physiologically active substances when developing recipes with a functional orientation that positively affect human health, and when expanding the range of bakery products. Therefore, the body's ability to obtain protein from these products is limited [11].

In 2024, research has been done to replace some wheat flour with traditional soybean flour in the production of waffles to try to improve the physicochemical properties of the product [12].

Soybean flour contains 52-59% protein, about 38% of carbohydrates, including 15% soluble mono- and oligosaccharides and 13% polysaccharides, which can later be removed when obtaining soybean concentrate or isolate [12].

Functional foods are characterized by the presence of bioactive compounds, which are molecules that improve health through physiological mechanisms. The United States Food and Drug Administration (FDA) currently lacks a formal definition of functional foods. However, The Functional Food Center (FFC) has contributed to developing an improved and comprehensive definition of functional foods as well as a criterion for inducting a functional food. Functional foods are natural or processed food products that contain biologically active compounds [13].

Recently, there has been a rise of interest in studying the potential benefits of probiotics in improving metabolic health and weight management. Many studies further reveal the significance of gut microbiota diversity on obesity intervention. While many studies suggested that probiotic supplementation possesses a positive impact on reducing obesity, the results are still limited and inconclusive [14]. The chemical structure of some amino acids is shown in Figure 1.

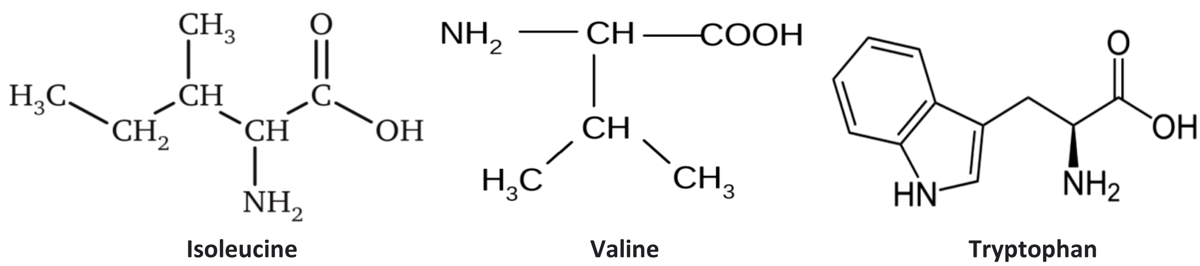


Figure 1: Chemical structure of amino acids.

MATERIALS AND METHODS

Plant materials: The research objective was the amino acid composition of hydroponically grown soybean flour, which was compared with the amino acid composition of other animal proteins. A new Dutch waffle technology with high biological value was developed using the obtained flour. Sampling of soybeans was carried out by G.S. Davtyan Institute of Hydroponics Problems.

Obtaining whole grain soybean flour: Soybeans were sorted, cleaned of extraneous impurities, and sieved through a sieve with a diameter of 10 mm. Then whole grains were salted to the size of 120 mm grains. The resulting whole-grain mixture is sieved. Sifting is carried out using a sieve with 3.5 mm diameter holes. No deodorization process is used in obtaining soybeans because one of the advantages of hydroponically grown soybeans is the absence of a characteristic odor.

Experimental sample moisture determination: The moisture content of the resulting samples of raw soybeans, flours, and wafers were determined using a state-of-the-art Kern DAB analyzer with an accuracy of 0.95. Samples were dried in SOFT mode, intended for complete dehumidification. The drying temperature continuously rose to 120^{0}C until the samples were dried and the given temperature was maintained.

The samples were placed on a drying tray with a flat, evenly distributed surface. At least 15 grams of grains were placed in the bowl [15].

Finished products: Hydroponically obtained soybean flour was tested for making wafers. For this purpose, the necessary materials were provided by the Scientific Research Institute of Food Science Biotechnology, using raw materials acquired through the framework of the base financing program.

Protein determination: In food analysis, the concept of "protein" often refers to the amount of total nitrogen determined by the Kjeldahl method multiplied by the appropriate conversion factor (6.25). Kjeldahl's method is one of the most famous and most widely used. The modern analyzer system (Gerhardt analytical systems) was used for the research. The analyzer system consists of 2 devices-Digestion + fume suction and Distillation + Titration. This is a standard method, the essence of which is as follows. The dissolved sample is oxidized with hot concentrated sulfuric acid, of which the bound nitrogen is converted into ammonium ion. A strong base is added to the resulting solution, yielding ammonia. The amount of ammonia is determined by the titrimetric or photometric method. The method consists of 3 stages:

1. Dissolution. The organic sample is dissolved in boiling sulfuric acid in the presence of a catalyst. At the same time, the nitrogen contained in the protein turns into ammonium sulfate $(NH_4)_2SO_4$.

Protein + H_2SO_4+ catalyst

$(NH_4)_2SO_4$ +CO_2+H_2O...

2. Steam distillation. Under the influence of hot steam, in the presence of a base (NaOH), which is expelled and absorbed by boric acid.

$(NH_4)_2SO_4$ + 2NaOH Na_2SO_4+ H_2O + $2NH_3$

NH_3 +H_3BO_3 $(NH_4)H_2BO_3$

3. In titration. Ammonium salt and boric acid are titrated with hydrochloric acid solution:

$(NH_4)H_2BO_3$ + HCL H_3BO_3+NH_4CL

The nitrogen content in the examined sample is calculated based on the amount of acid spent on trituration. The result is multiplied by the protein factor to get the protein content [16].

Determination of amino acid score: This is determined by different methods. One available method is to calculate the amino acid score. The nutritional value of any protein is compared to a reference protein whose amino acid composition is balanced and ideally meets the human body's requirement for each essential amino acid. The unit of amino acids can be equal to:

- 1.0 if its content exactly conforms to the standard
- More than 1.0 if of excess content
- Less than 1.0 if insufficient amino acid content

Limited amino acids are those essential amino acids whose amino acid unit is less than 1 [16].

Determination of wetness: This method determines the degree of wetness of cookies, galettes, and crackers.

The device consists of cells with three compartments and a water tank. The cells are mesh constructions measuring 93 × 80 × 60 mm, and the water tank is 150 mm high and 140 mm in diameter. The cell and water tank are made of stainless metal.

One test product (divided into two parts) is placed in three compartments of the dry chamber and weighed with an accuracy of 0.01g. Then, the cell is removed from the water and kept in an inclined position for complete removal by the following formula:

$$D = \frac{m - m_1}{m_2 - m_1} \cdot 100\ \%$$

Where m is the mass of the cell with the wetted product, g.

m_1- is the mass of the empty plug, g.

m_2- is the mass of the cell with dry product, g.

The analysis is performed three times, and the arithmetic mean is calculated to obtain the result [17].

Density determination: For this purpose, the samples are weighed, and then their volume is measured. To do this, the container is filled with millet to the top, cutting off the excess with the use of a ruler. Then, a part of the millet is emptied, and the wafer mass is placed; then, the rest of the millet is poured on top, and the excess is cut again with a ruler. The millet, which did not enter the container, is poured into the volumetric cylinder, and the volume is measured. The density of the product is determined by the following formula:

$$x = \frac{m}{\mathrm{P}}$$

Where m - is the mass of the sample, g.

P- is sample volume, cm^3 [18].

Analysis of amino acids using HPLC: HPLC is the method of choice for determining AAs in food samples due to its ability to offer a high-throughput feature, provide good separations of AAs in a relatively short time, and quantify low levels of AAs with good sensitivity. Analysis of AAs using HPLC consisted of three main steps:

1. Hydrolysis of individual AAs from the protein backbones,
2. Separation of individual AAs using HPLC procedure
3. Detection and quantification of the separated AAs

The sample preparation's main objective in analyzing AAs using HPLC is to release AAs completely from the sample matrix with minimum interferences resulting in the acceptable recoveries of analyte(s). The AA's hydrolysis procedure is simple, in which the use of acids (HCl) or bases of 4.2 M NaOH (105°C for 20 hrs) at a certain time and temperatures was capable of hydrolyzing the peptide bond between adjoining AAs to release free AAs.

To analyze AAs in protein hydrolysates from food samples over the last decades, HPLC methods using specific UV-Vis and fluorescence detectors have been applied [19].

Statistical analysis: To collect the data, scientific databases, including ISI Web of Knowledge, ResearchGate, Elsevier, and Scopus, as well as several traditional texts and books, were searched.

Field experiments were replicated 3 times. All analyses were carried out in four copies, and the data were expressed as means ± standard deviation.

The results were compared using parametric analysis of ANOVA data. Bonferroni's accuracy has been applied to more than two groups. The Mann Whitney test was employed for statistical analysis in cases where the data distribution deviated from normality. SPSS Version 16 was used to make the statistical calculations

RESULTS AND DISCUSSION

Comparative study of the amino acid composition of raw materials containing protein: Before using soybean flour as a protein source in wafers, its amino acid composition was investigated and compared with other foods that also contain protein and are used in flour confectionery. At the same time, 1g in food was used as a basis for comparison. The ideal essential amino acid content in protein was defined by FAO experts (FAO, Food and Agriculture Organization) and WHO (WHO, World Health Organization) in 1973 and updated in 1985 [20-21]. The amino acid composition of the studied foods is presented in Table 1.

Table 1: The comparative assessment of essential amino acids, which are contained in proteins of plant and animal origin.

Amino acid composition	The daily requirement of the human body for essential amino acids, g.	The content of essential amino acids in 100 g of the product in grams			
		Whole grain flour from soybeans grown on by hydroponics method	Wheat flour high type	Chicken eggs	Whole milk
Isoleucine	3-4	1.685±0.03	0.345±0.01	0.668±0.03	0.168±0.03
Leucine	4-6	2.873±0.01	0.698±0.01	1.078±0.01	0.309±0.01
Leucine	3-5	2.304±0.01	0.215±0.01	0.908±0.01	0.265±0.01
Methionine+Cysteine	2-4	0.487±0.01	0.175±0.01	0.376±0.01	0.079±0.01
Phenylalanine+Tyrosine	2-4	1.819±0.01	0.506±0.01	0.679±0.01	0.164±0.01
Threonine	2-3	1.501±0.01	0.274±0.01	0.549±0.01	0.139±0.01
Tryptophane	1	0.516±0.01	0.120±0.01	0.159±0.01	0.038±0.03
Valine	3-4	1.756±0.03	0.406±0.03	0.846±0.03	0.210±0.03

*P<0.05

The biological value of food is an indicator of protein quality, reflecting the degree to which its amino acid composition corresponds to the amount of amino acids required by the human body for protein synthesis. The chemical unit of amino acids (AS) is used to determine the biological value of dietary protein. The amino acid unit of a protein (AS) is the amount of essential amino acids (EAS) in the protein under study. This is the ratio of the same number of amino acids in an ideal protein. The calculation of the amino acid unit is performed according to the following formula [22]:

$$AS = \frac{EA\ 1g.\ protein,\ \ mg/g}{EA\ 1g.\ in\ ideal\ protein, mg/g} * 100$$

The amino acid composition of essential amino acids in the main raw materials was studied and presented in Table 2.

Table 2: The content of essential amino acids in the main raw materials for Dutch waffles.

Amino acid composition	The amount of essential amino acids which is contained in 1g. ideal protein, mg	The content of amino acids in raw materials by protein, mg/1 g			
		Whole grain flour of soy		Wheat flour of high type	
		Mg/g in protein	The score of amino acids, %	Mg/g in protein	The score of amino acids, %
Valine	50	50.0	100	47.8	95.6
Isoleucine	40	42.4	106	49.8	124.5
Leucine	70	63.2	90.2	74.6	106.5
Leucine	55	50.1	91.0	24.4	44.3
Methionine + Cysteine	35	25.8	73.7	36.6	104.5
Threonine	40	23.1	57.75	29.9	74.75
Tryptophane	10	11.6	116	10.5	105
Phenylalanine + Tyrosine	60	63.1	105.1	84.4	140.6

Comparative assessment of the moisture content of the main raw materials: Before defining the compositional parameters, it is necessary to first examine the moisture indicators of the main type of dough at the given time as the structural and mechanical properties of the dough mass are determined by moisture content of the grain and flour. Since informational literature and normative documents do not provide moisture index data for whole grain soybean flour and hydroponically grown soybeans, it was necessary to determine this index experimentally. The obtained data was compared with the data of wheat flour and defatted soybean flour. The results are presented in Figure 2.

According to the results, the moisture content of soybean whole grains is lower at 7.99%. This is a favorable condition for obtaining a solid waffle dough semi-finished product because soybean flour has high water absorption and storage properties. This allows the dough to mold to the cooking surface of the device during baking and will easily come out of the device without the use of shape preservation additives.

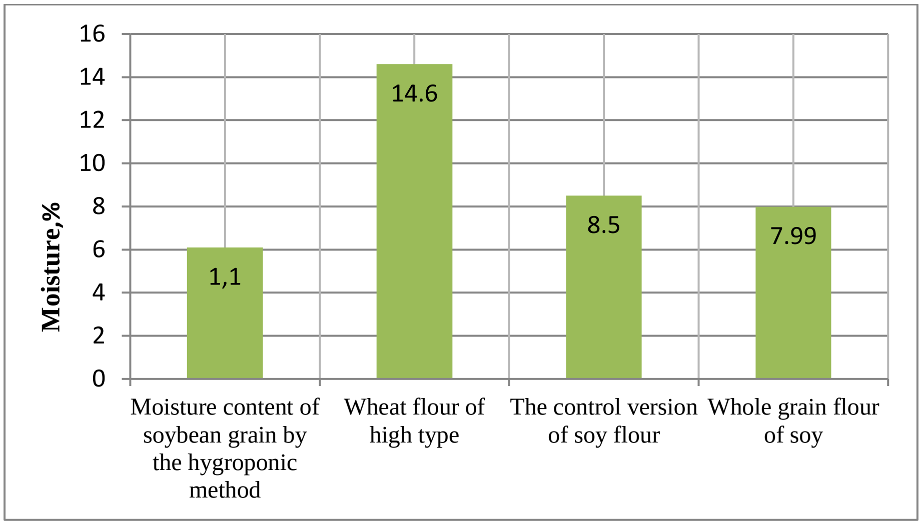


Figure 2: Determination of moisture content of wheat and soy flour.

Dutch waffle recipe development: When developing the waffle recipe, the primary task was not to use any alternative improver used to ensure quality and stability. Technological parameters have been developed according to this principle, so that a high-quality product can be obtained without using the food additives that are typically used to produce traditional products.

Since the new wafer product had to also be tested in a small sample, which is an analog of the newly designed wafer apparatus, the calculations were made according to the dosage of the apparatus. The calculations are presented in Table 3.

Table 3: Calculation of waffle ingredients depending on the preparation of one portion.

Name of the raw material	Required doses, g
The necessary raw material for preparing the dough	
Wheat flour of high type	490 /or 70%/
Whole grain flour of soy	210 /or 30%
Powdered sugar	220
Butter	300
Whole milk	135
Doshab	15
Chicken eggs	22
Baking powder	3
Cinnamon	4
Vanilla	1
The necessary raw materials for the preparation of caramel filling	
Invert syrup	176
Powdered sugar	112
Sugar /Brown sugar/	36
Butter	60
Cinnamon	1
Vanilla	1
Salt	1

Preparation of waffles semi-finished products and development of technological parameters: The peculiarity of the processed waffle dough is that, unlike traditional waffle dough, it does not have a liquid composition [22].

This is due to the uniqueness of the dough formation. Waffle dough forms evenly if it has low viscosity. Its moisture content is usually 58-65%. To obtain dough with a stable consistency, the flour should have a weak gluten content, and the gluten content should not exceed 32% [22-24].

The option of partially using soy flour also makes it possible to weaken the quality of the adhesive, resulting in a homogeneous and stable waffle sheet. To define the optimal version of soy flour application, three experimental samples were examined. In each version, soy flour was refined at the rate of 20%, 30%, and 40% by dry matter mass. At the same time, 20%, 30%, and 40% rations of high-quality wheat were taken out from elsewhere.

Strictly observing the sequence of addition of raw materials, they are poured into the dough mixer, except for the wheat and soybean mixture. The duration of mixing is 20 minutes. Then, the flour mixture is gradually added, and the dough rests for 1 hour. Unlike the traditional liquid dough, in the researched versions, the dough is obtained with a soft consistency, which can be divided into balls. The weight o should not exceed 28 grams because the baked product should have a diameter of 8 cm.

One of the tasks of the research work was also to test the designed waffle baking device, which is in the design stage and technical corrections. Therefore, it was necessary to develop a dough composition and parameters that will enable the device to operate fully. Baking is carried out in a domestically designed waffle device at up to 200^{0}C for 1 minute. The mentioned device was designed and assembled by the engineers of the Vanadzor Technology Center and was tested by the specialists of the Scientific Research Institute of Biotechnology and Nutrition. Figure 3 shows the baking process and baked sample of the experimental Dutch waffle machine. The physiochemical parameters of the studied samples are presented in Table 4.

(a) 

(b) 

Figure 3: An experimental model of a Dutch waffle machine: The baking process (a), baked sample (b).

Table 4: Physicochemical parameters of the studied samples.

Quality indicators of waffle sheets	Sample of waffle sheets			
	Control sample	Sample No. 1 (with a soy flour content of 20%)	Sample No. 2 (with a soy flour content of 30%)	Sample No. 3 (with a soy flour content of 40%)
The mass fraction of carbohydrates by dry substances, %	50,77±0,1	36,13±0,1	33,14±0,1	30,15±0,1
The mass fraction of protein by dry substances, %	5,72±0,1	8,19±0,1	9,43±0,1	10,66±0,1
Density/sm³	0,34±0,01	0,36±0,01	0,38±0,01	0,40±0,01

*P<0.05

Two balls are simultaneously placed in the device and immediately after baking, the semi-finished products are divided into two parts from the middle. During baking, the dough softens and a product with a diameter of 8 cm and a golden color is obtained. Caramel filling is poured on one layer, and the other layer is placed on top.

Thickening of the caramel filling involves mixing invert syrup and powdered and brown sugar in a thick-walled steel bowl. Then it was placed on a heat source and heated it up to 110^{0}C, until the amount of dry matter was 87%. After taken out of the jar, add butter, vanilla, cinnamon, and salt. Then the mass is cooled to 45-50^{0}C.

The study of the quality indicators of waffles according to the increase in the proportion of additives: The change of the initial quality indicators was evaluated according to the physicochemical indicators of wafer sheets. The data is presented in Table 3.

According to the recorded results, the sample with the addition of 30% soy flour had the most favorable results among the samples of waffle sheets, which did not lose to the physicochemical indicators of traditional waffles and were more improved.

From the results of the studies, it became clear that the moisture content of the semi-finished product decreases with the amount of soy flour addition, though it remains within the permissible limits for waffles. The mass fraction of protein also increased by 3.71% with the addition of 30% soy flour. The mass fraction of carbohydrates decreased by 17.63% with the addition of 30% soy flour, which is considered a positive outcome. The density index is regarded as an important metric because it forms the structural-mechanical property for new products. The indicators revealed that the density increases with the addition of soy flour, resulting in the obtained to have a denser texture and a heavier and solid composition. By observing this index, it can be concluded that it is more appropriate to replace up to 30% soybean flour. If this is exceeded, the product loses its structural and mechanical positive characteristics.

To get a more solid picture of the structural properties of the investigated production, their wettability and plasticity indicators were also studied. The results are presented in a graphic image shown in Figure 4.

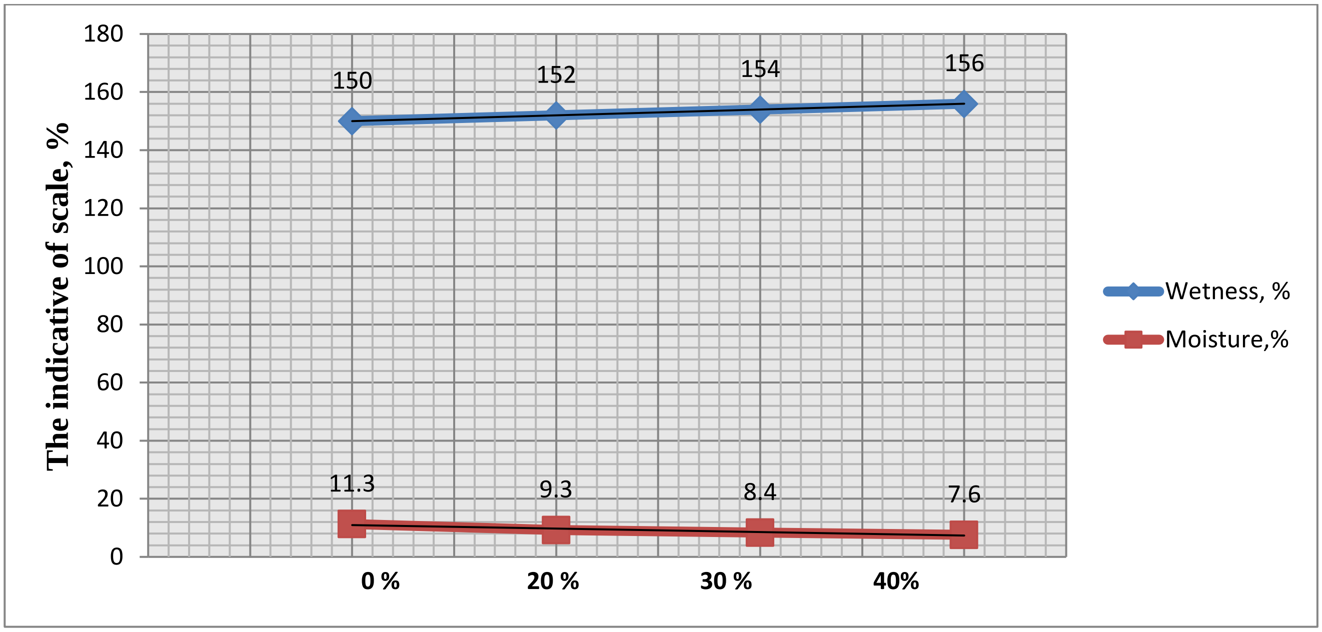


Figure 4: Changes in the moisture and wettability of the studied samples depending on the added dose of soy flour.

With the increase in the amount of soy flour, a larger amount of product was obtained, which is economically efficient. However, the index of plasticity decreases with the increasing amount of soybean flour. The product is less plastic, which negatively affects its appearance and fragility.

Studies are being conducted on the chemical composition of finished products, changes in their biological value, and shelf life. Information about the results will be published in another issue of the bulletin.

CONCLUSIONS

The technology and recipe of the Dutch waffle from the using whole-grain soy flour, which was obtained from hydroponically grown soy seeds, has been developed. A new technology has been tested for a new waffle maker, which will be produced in the near future. The technology and formulation of the waffle dough were adapted to the principles of operation of the device in such a way that a high-quality product was obtained without the use of alternative chemical.

The article evaluates the amino acid composition of hydroponically and locally produced soybean flour, compared with the amino acid composition of other raw materials used in confectionery. The optimal dose of soy was determined according to the defined composition. To obtain a high-quality product, the amount of soybean used was 30%, according to the amount of high-quality wheat flour. Waffle recipes and technological parameters have been developed and tested on a new device designed for waffles. The ingredients have been selected so that various quality assurance stabilizers and food additives are not applied. Whole soybean flour is rich in amino acids like valine and tryptophan, compared to whole wheat flour. It increases the protein value of the waffle, giving it a functional property. The test results of the device at the design stage were positive, indicating the developed technology was completely adapted to the working principles of the device and ensured production and work efficiency. The scientific and experimental results can be implemented in the domestic production market, contributing to the food chain in three development directions: hydroponic soybean cultivation, new device production, and the introduction of a new type of waffle product. Thus, our studies have important industrial significance and can be used as a favorable means of developing souvenir production.

List of abbreviations: RA- Republic of Armenia; EAS- essential amino acids; AS- Amino acid score; HPLC- High Performance Liquid Chromatography.

Authors' contributions: Narine Hovhannisyan is the main author and conductor of the research. Viktor Abrahamyan, Valery Grigoryan, Arevik Abovyan, and Liana Grigoryan contributed to the study of the amino acid composition of products and comparative evaluation. Asya Badalyan contributed to the statistical processing. Suzanna Abrahamyan contributed to the preservation of correspondence.

Competing interest: The authors declared that there is no competing interest.

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