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DEVELOPMENT OF THE MACHINE AND APPARATUS SCHEME FOR THE PRODUCTION OF HEALTHY, CRISPY AND SUGAR FREE FLAKES FOR THE CONFECTIONERY INDUSTRY

РОЗРОБКА МАШИННО-АПАРАТУРНОЇ СХЕМИ ВИРОБНИЦТВА КОРИСНИХ, ХРУСТКИХ ТА БЕЗ ЦУКРУ ПЛАСТІВЦІВ ДЛЯ КОНДИТЕРСЬКОЇ ПРОМИСЛОВОСТІ

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Abstract *This article presents the development of a machinery and equipment scheme for producing nutritious, crispy flakes without the addition of sugar, suitable for use in the confectionery industry. It describes current trends in the demand for healthy food products and explores the substitution of traditional ingredients (sugar, wheat flour, confectionery fats) with alternatives, specifically gluten-free flours, natural sweeteners, and beneficial fats. The proposed technology incorporates the use of a tunnel dehydrator and conveyor drying units to manufacture flakes with a low glycemic index. The selection of raw materials and their processing methods are justified to preserve the nutritional properties of the product and ensure a stable texture. The research findings can be applied to implement innovative solutions in the confectionery industry and to satisfy consumer demand for dietary and healthy food products.*

Keywords: *nutritious flakes, production technology, machinery and equipment scheme, tunnel dehydrator, confectionery industry, sugar-free.*

Introduction

The modern confectionery industry is facing an increasing demand for healthy and dietary products, driven by the growing consumer awareness of the impact of nutrition on health [1]. Traditional confectionery products typically contain significant amounts of sugar, wheat flour, and confectionery fats, which are associated with the risk of developing obesity, diabetes, and cardiovascular diseases [2][3]. Therefore, there is an urgent need to create alternative products that satisfy consumers' taste preferences without adverse health effects.

Recent scientific research has focused on finding substitutes for traditional ingredients, such as natural sweeteners [4], gluten-free flour mixtures [5], and beneficial fats [6]. However, the implementation of these new components into mass production requires the adaptation of existing technological processes and the development of specialized equipment [7].

The aim of this article is to develop a machinery and equipment scheme for a production line that manufactures confectionery products without the use of sugar, wheat flour, and confectionery fats. This will facilitate the introduction of new technologies into production and meet the market demand for healthy confectionery products.

During the research, an analysis of alternative ingredients will be conducted, their impact on technological processes will be studied, and the requirements for equipment to process them will be determined. It is expected that the results of this work will serve as a foundation for the industrial implementation of innovative lines for producing healthy confectionery products.

Glycemic Index as a Measure of the Nutritional Value of Confectionery Products

The glycemic index (GI) is an indicator that reflects the impact of carbohydrate-containing foods on blood glucose levels. It characterizes the speed at which carbohydrates are converted into glucose after the consumption of a product [8]. Foods with a high GI cause sharp increases in blood sugar levels, which can lead to insulin spikes and subsequent energy drops [9]. In contrast, foods with a low GI provide a more stable and prolonged energy level.

In the context of confectionery products, the use of low-GI ingredients is important for creating products that not only satisfy taste preferences but also help maintain healthy blood glucose levels [10]. This is particularly relevant for individuals with diabetes, metabolic syndrome, or those aiming to control their weight [11].

Selection of Raw Materials with a Low Glycemic Index

To develop healthy confectionery products without the use of sugar, wheat flour, and confectionery fats, a range of alternative ingredients with low GI and high nutritional value were selected.

1. Dry Raw Materials

- Millet Flour: Has a low GI and is rich in magnesium, phosphorus, and B vitamins [12]. Suitable for making bakery products and cookies.
- Arrowroot Flour: A natural thickener with a low allergen content. Used to improve the texture and structure of products [13].
- Whole Grain Barley Flour: Rich in soluble fiber beta-glucan, which helps reduce cholesterol and stabilize blood sugar levels [14].
- Hemp Flour: A source of complete plant protein, omega-3 fatty acids, and fiber. Enhances the nutritional value of products [15].
- Chickpea Flour: Has a low GI, high protein, and fiber content. Improves the structure and taste of products [16].
- Flaxseed Flour: Rich in omega-3 fatty acids and lignans. Used as an egg substitute in recipes [17].
- Ezekiel Flour: A mixture of sprouted grains and legumes that increases the bioavailability of nutrients and lowers the GI [18].
- Buckwheat Flour (Dark and Light): Gluten-free, has a low GI, and is rich in rutin, which strengthens blood vessels [19].
- Whole Grain Rye Flour: Contains more fiber and less gluten compared to wheat flour. Promotes prolonged satiety [20].
- Graham Flour: Whole grain wheat flour with coarse milling and high fiber content [21].
- Lentil Flour: High in protein and fiber, low GI. Improves the texture and nutritional value of products [22].

2. Raw Materials in the Form of Grains and Legumes

2.1. Grains and Pseudocereals

- Millet: A gluten-free grain with a low GI, rich in magnesium and phosphorus [12].
- Flaxseeds: A source of omega-3 fatty acids, lignans, and fiber. Can be used in ground form [17].
- Sesame Seeds: Rich in calcium, magnesium, and antioxidants. Enhances the flavor characteristics of products [23].

- Barley: Contains beta-glucan and has a low GI. Promotes cardiovascular health [14].
- Quinoa: A pseudocereal with complete protein, containing all essential amino acids. Has a low GI [24].
- Amaranth, Teff, Fonio: Ancient grains with high nutritional value and low GI [25].

2.2. Legumes

- Lentils, Peas, Chickpeas: Rich in protein, fiber, and micronutrients. Have a low GI and enhance satiety [16][26].
- Beans (Red, White, Black, Pinto, Adzuki): High in protein and fiber. Help reduce cholesterol levels and stabilize blood sugar [26].
- Lupin, Fava, Black Beans: Have a unique amino acid profile and low GI [27].
- Butterfly Peas, Garbanzo Beans, Lima Beans: Improve the texture of products and add nutritional value [28].

3. Raw Materials Rich in Fiber

- Vegetables: Pumpkin, carrot, cabbage, beet, celery, zucchini, parsnip, sweet potato, asparagus, tomato. Rich in dietary fiber, vitamins, and minerals. Low GI and low in calories [29].
- Fruits: Guava, papaya, mango, dates, figs, dried fruits. Provide natural sweetness, fiber, and antioxidants [30].

Role of Fiber: Dietary fibers slow down the absorption of carbohydrates, which helps reduce the GI of products. They also improve digestion and contribute to a healthy gut microbiota [31].

Justification of the Glycemic Index as a Measure of Nutritional Value

The use of low-GI raw materials in confectionery products allows for:

- Blood Glucose Control: Low-GI products do not cause sharp spikes in blood sugar levels, which is important for the prevention and management of diabetes [32].
- Increased Satiety: High protein and fiber content promotes prolonged satiety, which can aid in weight control [33].

- Improved Metabolic Indicators: Reducing the intake of simple carbohydrates positively affects cholesterol and triglyceride levels [34].
- Nutritional Value: Alternative ingredients are rich in vitamins, minerals, and antioxidants, enhancing overall dietary quality [35].

Replacing traditional ingredients with low-GI raw materials is a justified approach for creating healthy confectionery products. The selected ingredients not only lower the GI of products but also increase their nutritional value by adding protein, fiber, and beneficial fats. This aligns with current trends in healthy eating and meets consumer demands for high-quality and safe food products.

Review of Recent Studies and Publications

In the contemporary scientific community, there is a growing interest in developing confectionery products with a low glycemic index (GI). This trend is driven by increased attention to issues such as obesity, diabetes, and other metabolic diseases associated with excessive consumption of simple carbohydrates [36].

Studies indicate that the use of alternative types of flour with low GI, such as millet, chickpea, flaxseed, and buckwheat flour, can significantly reduce the glycemic response of confectionery products. For instance, replacing wheat flour with buckwheat flour in cookie recipes leads to a 20–30% reduction in the product's GI [37]. This reduction is attributed to the higher fiber and protein content in alternative flours.

Leguminous crops, such as lentils and chickpeas, also attract researchers' attention. Adding chickpea flour to bakery products enhances their nutritional value and lowers the GI [38]. This is due to the high content of soluble fiber and resistant starch in legumes.

The use of pseudocereals (quinoa, amaranth, teff) is becoming increasingly popular. These crops contain complete proteins and have a low GI, making them ideal ingredients for healthy confectionery products [39].

Vegetables and fruits with high fiber content, such as pumpkin, carrot, and dates, are also utilized to enrich food products. Incorporating pumpkin puree into baked goods not only reduces the product's GI but also increases its antioxidant activity [40].

In addition to ingredient selection, research focuses on technological processes that can influence the GI of the final product. For example, thermal processing methods and the degree of flour milling can alter the availability of carbohydrates for fermentation, thereby affecting the glycemic response [41].

Studies emphasize the importance of combining different types of raw materials to achieve an optimal balance between low GI and appealing organoleptic properties [42]. Using blends of flours from various grains and legumes allows for the creation of products with improved amino acid profiles and texture.

It is also noteworthy that recent publications highlight the use of natural sweeteners with low glycemic indices, such as stevia and erythritol. These sweeteners enable the reduction or complete elimination of added sugar from recipes, contributing to lower calorie content and GI of the products [43].

Conclusions from the Literature Review:

- The effectiveness of using alternative types of flour and low-GI raw materials to reduce the glycemic response of the body has been confirmed.
- Combining different ingredients allows for optimizing not only the nutritional value but also the taste and texture characteristics of products.
- Technological aspects of production significantly influence the GI and require further research to develop optimal processes.
- The positive impact on consumer health is supported by numerous clinical studies demonstrating reduced risks of developing metabolic diseases when consuming low-GI products.

Conclusion

The review of recent studies and publications indicates significant scientific and practical interest in developing confectionery products with a low glycemic index. Utilizing raw materials rich in fiber, protein, and beneficial fats is a promising direction in the food industry. This approach aligns with current trends in healthy eating and enables the creation of products that combine high sensory qualities with health benefits.

Objective of the Study

The objective of this research is to develop and present a machinery and equipment scheme to produce confectionery products without the use of sugar, wheat flour, and confectionery fats, utilizing alternative raw materials with a low glycemic index (GI).

Current trends in the food industry indicate a growing need for products that combine high nutritional value with consumer health safety. Traditional confectionery products are often associated with high levels of simple sugars and saturated fats, which can negatively impact health and contribute to the development of metabolic diseases. Therefore, there is a necessity to create innovative products that meet the requirements of healthy eating without compromising on taste quality.

The main objectives of the study include:

- *Analysis of Alternative Raw Materials Properties*: Investigate the physicochemical and technological characteristics of low-GI raw materials, such as millet flour, chickpea flour, flaxseed flour, as well as various legumes and pseudocereals. Evaluate their impact on the organoleptic and structural properties of the final products.
- *Development of the Technological Process*: Create an efficient technological process that accounts for the specificities of the selected raw materials. This includes optimizing parameters for raw material preparation, dehydration, shaping, and drying to preserve nutritional substances and ensure high product quality.
- *Design of the Machinery and Equipment Scheme*: Develop a detailed scheme of the necessary equipment and technological lines required for the production of such confectionery products. Consider the characteristics of processing alternative raw materials and the integration of innovative technologies, such as a tunnel dehydrator with an applicator and conveyor drying units.

It is anticipated that the research results will contribute to:

- *Implementation of Innovations in the Confectionery Industry*: The proposed machinery and equipment scheme will enable manufacturers to expand their product range and meet the demand for healthy confectionery products.
- *Enhancement of Consumers' Quality of Life*: Providing access to healthy and tasty products will promote improved dietary habits among the population and reduce

the risk of developing chronic diseases.

• *Development of Scientific Knowledge Base*: The study will add to the knowledge regarding the use of alternative raw materials and advanced technologies in the food industry, serving as a foundation for further scientific research and developments.

• *Sustainable Development*: Rational resource utilization and the implementation of energy-efficient technologies align with the principles of sustainable development and corporate environmental responsibility.

Thus, the objective of the study is not only to technically develop a production line but also to adopt a comprehensive approach to creating products that meet contemporary standards of quality, safety, and environmental sustainability. This opens new opportunities for the innovative development of the confectionery sector and fulfills consumer demands for healthy nutrition.

Materials and methods

Analysis of Alternative Raw Materials

The selection of low glycemic index (GI) raw materials is crucial for the development of confectionery products that support the maintenance of stable blood glucose levels and possess enhanced nutritional value. This section provides a detailed analysis of the physicochemical and technological properties of the alternative raw materials utilized in production.

1. Dry Raw Materials

1.1. Millet Flour

Millet flour is a gluten-free product with a low GI. It is rich in B vitamins, magnesium, and phosphorus. Millet contains a high amount of dietary fiber, which contributes to improved digestion and reduced risk of cardiovascular diseases [44].

1.2. Arrowroot Flour

Arrowroot flour is derived from the rhizomes of tropical plants. It is used as a natural thickener and has a neutral taste. The flour is easily digestible and suitable for individuals with allergies or gluten sensitivity [45].

1.3. Hemp Flour

Hemp flour is a source of complete plant protein, containing all essential amino acids. It is also rich in omega-3 and omega-6 fatty acids in an optimal ratio, fiber, and micronutrients [46].

1.4. Chickpea Flour

Chickpea flour has a low GI and a high content of protein and fiber. It enhances the structural properties of dough and adds a nutty flavor to products. The use of chickpea flour contributes to reducing the glycemic load of products [47].

1.5. Flaxseed Flour

Flaxseed flour is rich in alpha-linolenic acid (omega-3), lignans, and fiber. Adding flaxseed flour to food products can reduce the risk of cardiovascular diseases and improve the lipid profile of blood [48].

1.6. Buckwheat Flour

Buckwheat flour is gluten-free and has a low GI. It is rich in rutin, which strengthens capillaries and possesses antioxidant properties. Buckwheat contains a high amount of protein with a favorable amino acid profile [49].

2. Raw Materials in the Form of Grains and Legumes

2.1. Grains and Pseudocereals

2.1.1. Quinoa

Quinoa is a pseudocereal with a high content of complete protein and a low GI. It contains lysine and methionine, which are often limiting amino acids in plant proteins [50].

2.1.2. Amaranth

Amaranth is rich in protein, dietary fiber, and minerals. It possesses antioxidant properties and contributes to lowering cholesterol levels [51].

2.2. Legumes

2.2.1. Lentils

Lentils have a low GI and a high content of protein and fiber. They contain resistant starch, which positively affects the gut microbiota [52].

2.2.2. Chickpeas

Chickpeas are a source of protein, fiber, vitamins, and minerals. They help reduce blood glucose and cholesterol levels, as confirmed by clinical studies [53].

3. Raw Materials Rich in Fiber

3.1. Vegetables

3.1.1. Pumpkin

Pumpkin is a low-calorie product with a high content of dietary fiber, beta-carotene, vitamins, and minerals. Incorporating pumpkin puree into confectionery products enhances their antioxidant activity and lowers the GI [54].

3.2. Fruits

3.2.1. Dates

Dates are used as a natural sweetener and a source of dietary fiber. They contain antioxidants and minerals such as potassium and magnesium. Despite their sweet taste, dates have a moderate GI due to their high fiber content [55].

Conclusions of the Raw Materials Properties Analysis

The alternative raw materials examined in this study offer several advantages over traditional ingredients:

- Low Glycemic Index: Most selected ingredients have a low or moderate GI, which promotes stable blood glucose levels after consumption.
- High Protein Content: Hemp flour, quinoa, amaranth, and legumes are rich in plant-based protein with a complete amino acid profile.
- Rich in Dietary Fiber: High levels of soluble and insoluble dietary fibers improve digestion and contribute to a healthy gut microbiota.
- Presence of Bioactive Compounds: Antioxidants, polyphenols, omega-3 fatty acids, and other beneficial substances enhance the functional value of the products.
- Gluten-Free: Most alternative raw materials are gluten-free, making the products suitable for individuals with celiac disease or gluten intolerance.

Recommendations for Production Usage

- Combining Raw Materials: Blending different types of flours and grains allows for achieving an optimal balance of nutrients and improving the technological properties of dough.
- Technological Adaptation: Considering the specific properties of alternative

raw materials (e.g., absence of gluten), it is necessary to adjust recipes and production parameters accordingly.

- Additional Ingredients: Utilizing natural thickeners, emulsifiers, and low-GI sweeteners can enhance the texture and taste of products without compromising their health benefits.

The analysis of the properties of alternative raw materials confirms their potential for use in the production of confectionery products with improved nutritional characteristics. The selection of low-GI raw materials, high in protein and dietary fiber, aligns with current trends in healthy eating and meets consumer demands for safe and nutritious products.

Development of the Technological Process

The technological process for producing confectionery products without the use of sugar, wheat flour, and confectionery fats is based on the application of alternative raw materials with a low glycemic index (GI). This process includes several key stages (Figure 1):

1. Raw Material Preparation
2. Production of Flakes in a Tunnel Dehydrator
3. Shaping and Drying of Finished Products with Subsequent Cooling
4. Packaging

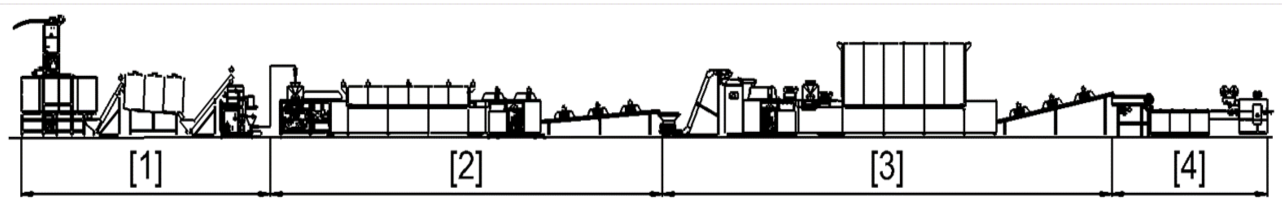

Figure 1 – Scheme of the Technological Process

1. Raw Material Preparation

Raw material preparation is a critical stage that affects the quality of the final product. Raw materials are divided into several types based on their physicochemical properties: dry raw materials (flour), legumes, and high-fiber raw materials.

1.1. Dry Raw Materials (Flour)

Alternative types of flour, such as millet, buckwheat, chickpea, flaxseed, and other cereals, undergo sieving and, if necessary, drying to an optimal moisture level [56]. This ensures uniformity and improves subsequent technological properties.

1.2. Leguminous Crops

Lentils, chickpeas, beans, and other legumes are cleaned, washed, and soaked to facilitate grinding [57]. They are then ground to a flour or paste state, which increases the bioavailability of nutrients.

1.3. High-Fiber Raw Materials

Vegetables and fruits, such as pumpkin, carrot, and beet, are washed, peeled, and processed into puree [58]. This puree is added to the recipe to enhance nutritional value and improve the organoleptic properties of the product.

2. Production of Flakes in a Tunnel Dehydrator

The prepared raw materials are mixed to obtain a homogeneous mass and fed into the tunnel dehydrator. The tunnel dehydrator is equipped with an applicator that evenly spreads the mass onto the conveyor belt [59]. As the belt moves through the dehydrator, simultaneous drying and baking of the mass occur under controlled temperature and humidity parameters.

Temperature Regime: The temperature in the dehydrator is maintained within the range of 60–80°C, which preserves the bioactive compounds of the raw materials and ensures the necessary texture of the flakes [60].

Process Duration: The drying duration depends on the layer thickness and raw material composition and is determined experimentally to achieve optimal product properties.

3. Shaping and Drying of Finished Products with Subsequent Cooling

After exiting the dehydrator, the flakes are directed to the shaping stage.

Shaping: A shaping head is used to direct the flakes into special molds on a chain conveyor [61]. A flax-based binding syrup, which contains natural polysaccharides and mucilage substances, is applied to bond the flakes [62].

Drying: The shaped products pass through a conveyor drying unit, where final drying occurs at temperatures of 70–90°C [63]. This ensures the stabilization of the form and texture of the products, as well as extends their shelf life.

Cooling: After drying, the products are cooled to room temperature on a cooling conveyor or in cooling chambers [64]. Cooling prevents moisture condensation in the packaging and preserves product quality.

5. Packaging

The cooled products are directed to packaging.

Packaging Materials: Barrier packaging materials, such as multilayer films, are used to protect the products from external factors (moisture, oxygen, light) [65].

Labeling: The packaging is labeled with information about the composition, nutritional value, expiration date, and storage conditions in accordance with the regulatory requirements of the food industry.

Advantages of the Developed Technological Process

- Preservation of Nutrients: Using moderate temperatures during drying and baking helps preserve vitamins, minerals, and antioxidants in the raw materials.
- Product Naturalness: The use of flax-based binding syrup and the absence of artificial additives improve consumer perception of the product as natural and healthy.
- Functional Properties: Adding flax increases the content of omega-3 fatty acids and dietary fibers, which positively impacts health.
- Process Efficiency: Combining drying and baking stages in a single unit optimizes the production process and reduces energy consumption.

The developed technological process allows for the efficient use of alternative raw materials with a low glycemic index for the production of confectionery products with improved nutritional and functional characteristics. The application of modern equipment and control of technological parameters ensure high product quality and safety.

Design of the Machinery and Equipment Scheme

Designing a machinery and equipment scheme for the production of confectionery products without the use of sugar, wheat flour, and confectionery fats is a complex task that requires the integration of modern technologies and equipment. The main objective is to optimize the technological process using alternative raw materials with a low glycemic index, while ensuring high product quality and production efficiency.

The machinery and equipment scheme consists of two stages: production of flakes (depending on raw materials) and direct shaping of finished products.

Figure 2 presents the production line for producing flakes from dry raw materials based on the principle of direct mixing.

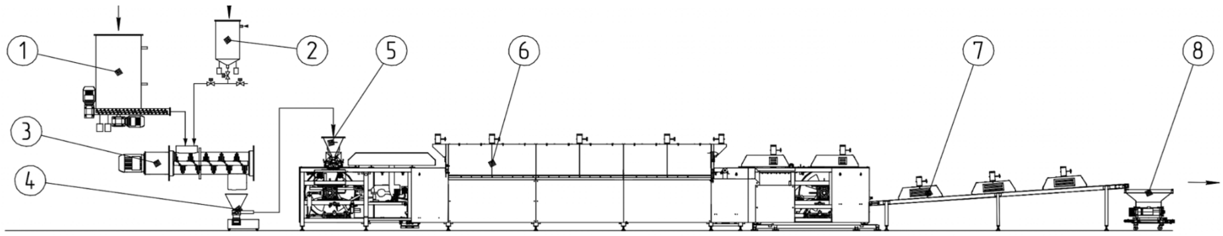

Figure 2 – Production Line for Producing Flakes from Dry Raw Materials Using Direct Mixing

Equipment:

1. Flour Feeder
2. Additional Ingredients Feeder
3. Continuous Mixer
4. Feed Pump
5. Sheet Forming Machine
6. Tunnel Dehydrator
7. Cooling Conveyor
8. Sheet Grinder

Principle of Operation of the Line:

1. Flour Feeder (1) supplies the main ingredient – flour from low glycemic index (GI) products, such as millet, whole grain flour, and others.

2. Additional Ingredients Feeder (2) adds supplementary ingredients (improvers, minerals, vitamins, and other additives).

3. Continuous Mixer (3) receives both dry and liquid components. A specialized dispenser adds water or oil (not shown in the scheme). This mixer ensures thorough

blending of the flour and additional ingredients, creating a homogeneous mass.

4. Feed Pump (4) conveys the mixed mass to the Sheet Forming Machine (5), where a thin sheet of the product is formed.

5. The formed sheet is directed to the Tunnel Dehydrator (6), where the drying process occurs. During drying, moisture is removed, resulting in a stable product.

6. The sheet is then moved along the Cooling Conveyor (7), where it is cooled to the desired temperature before the next processing stage.

7. In the final stage, the cooled sheet is delivered to the Sheet Grinder (8), where it is ground to the necessary size for further use or packaging.

Thus, the line operates in a continuous mode, automating the processes of mixing, shaping, drying, cooling, and grinding, which allows for the efficient production of flakes with high health benefits. Figure 3 presents a photo of the finished millet flour flakes.

Figure 3 – Flakes Produced from Millet Flour

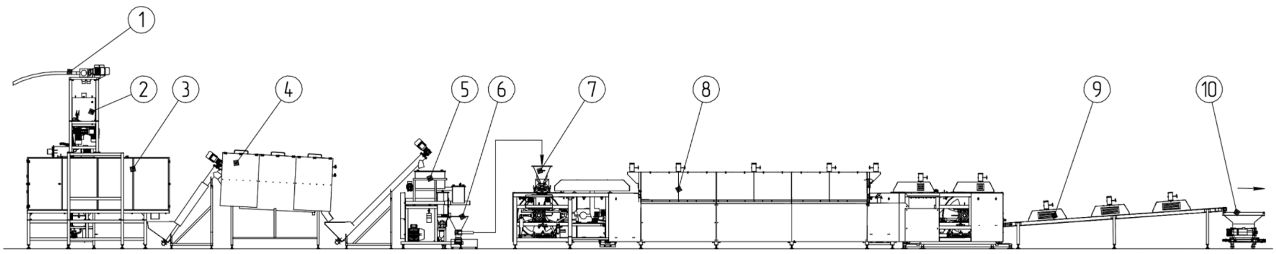

Figure 4 – Production Line for Producing Flakes from Grains or Legumes Based on Boiling and Soaking Principle

Figure 4 presents the production line for producing flakes from grains or legumes based on the boiling and soaking principle.

Equipment:

1. Raw Material Feed Pump
2. Raw Material and Additional Ingredients Feeder
3. Continuous Cooking Kettle (Cooker)
4. Washing Machine
5. Continuous Grinder
6. Feed Pump
7. Sheet Forming Machine
8. Tunnel Dehydrator
9. Cooling Conveyor
10. Sheet Grinder

Principle of Operation of the Line:

1. Raw Material Feed Pump (1) supplies the raw material into the feeder system. The raw material can be in the form of grains or legumes.

2. Raw Material and Additional Ingredients Feeder (2) adds the raw material and supplementary ingredients into the Continuous Cooking Kettle (3).

3. Continuous Cooking Kettle (3) is the key element of this line, where the raw material is cooked. The kettle is equipped with temperature zones that can be adjusted depending on the type of product and technology. Water for cooking is heated separately. The cooking process prepares the raw material for further processing.

4. After cooking, the obtained mass is transferred to the Washing Machine (4), where it is washed and cleaned of residual impurities.

5. The washed mass is then fed into the Continuous Grinder (5), which pulverizes the product to a porridge-like consistency.

6. After grinding, the mass is moved to the Feed Pump (6), which pumps it to the next stage.

7. Sheet Forming Machine (7) forms sheets from the prepared mass.

8. The formed sheets pass through the Tunnel Dehydrator (8), where the drying

process occurs. This stage removes moisture from the product, making it more stable for storage.

9. After drying, the sheets are moved along the Cooling Conveyor (9), where they are cooled to the optimal temperature.

10. In the final stage, the cooled sheets are delivered to the Sheet Grinder (10), where they are ground to the necessary size for further use or packaging.

Thus, the line performs all the main processes—from cooking and washing the raw material to forming and drying the flakes—ensuring a high-quality and stable product made from grain or legume raw materials. Figure 5 presents a photo of the finished lentil flakes.

Figure 5 – Flakes Produced from Lentils

Figure 6 presents the production line for producing flakes from raw materials with a high fiber content.

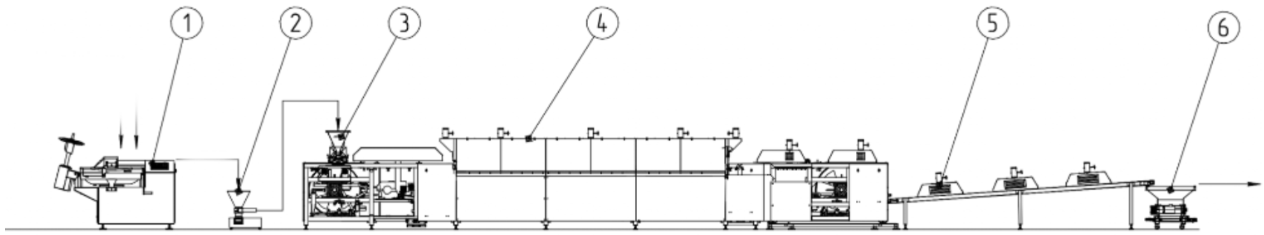

Figure 6 – Production Line for Producing Flakes from High-Fiber Raw Materials

Equipment:

1. Grinder (Cutter)
2. Feed Pump
3. Sheet Forming Machine
4. Tunnel Dehydrator
5. Cooling Conveyor
6. Sheet Grinder

Principle of Operation of the Line:

1. Grinder (Cutter) (1) supplies the raw material in its raw form to the feeder system. The raw material can be in the form of grains or legumes. This stage involves the mechanical processing of the raw material to convert it into a mass. The cutter ensures high-speed grinding, achieving a homogeneous consistency of the product.

2. The ground mass is transported by the Feed Pump (2) to the next stage, where it is directed to the Sheet Forming Machine (3). Here, thin sheets are formed from the prepared mass.

3. After shaping, the sheets pass through the Tunnel Dehydrator (4), where the drying process occurs. In the tunnel dehydrator, moisture is evaporated, making the product stable for long-term storage. The drying process can also affect the texture and crispness of the final product.

4. After drying, the sheets are moved to the Cooling Conveyor (5). This stage is necessary for gradually reducing the temperature of the product before further processing.

5. The cooled sheets pass through the Sheet Grinder (6), where they are ground to the required size. This can be done to prepare the product for packaging or further processing.

Thus, this technological line allows for the production of high-fiber flakes from raw materials, providing a complete processing cycle: from grinding the raw material to forming and drying the flakes. Figure 7 presents a photo of the finished flakes made from raw pumpkin.

Figure 7 – Flakes Produced from Raw Pumpkin with Addition of Natural Colorant

The flakes are further fed into a continuous production line for the direct manufacturing of finished confectionery products. **Figure 8** presents the production line for health-oriented confectionery products made from flakes without the use of sugar. The binding component consists of ground flaxseed combined with additional ingredients to produce the binding syrup.

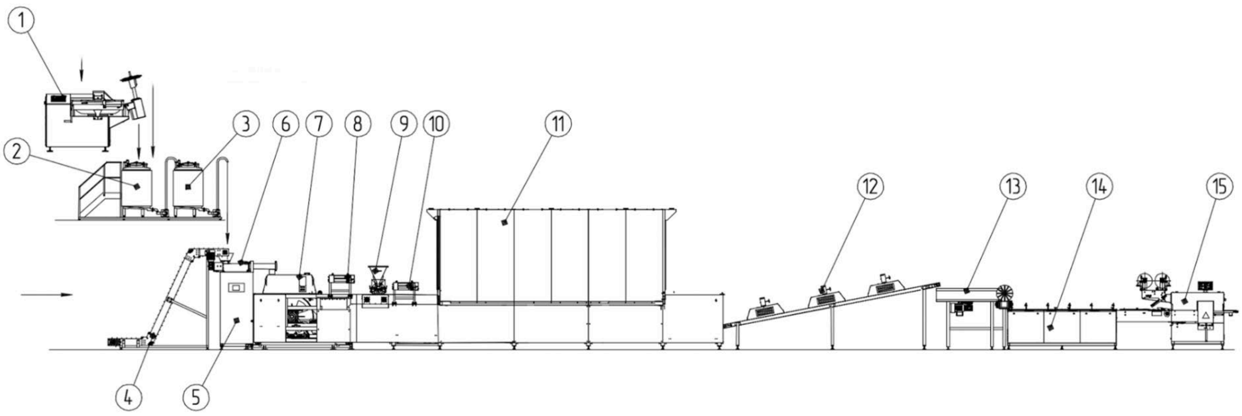

Figure 8 – Machinery and Equipment Scheme for the Production of Health-Oriented Confectionery Products from Flakes Without the Use of Sugar

Equipment:

1 - Flaxseed cutter

2 - Syrup preparation mixer

3 - Storage tank

4 - Feeding conveyor

5 - PLC control cabinet

6 - Continuous mixer

7 - Forming head

8 – Press

9 - Additional ingredients dispenser

10 – Press

11 - Drying complex

12 – Cooler

13 - Centrifugal accumulator-feeder

14 - Product feeding system

15 - Flow pack

Principle of Operation of the Line:

1. Feed Conveyor (4) supplies the finished sheets from the tunnel dehydrator to the conveyor-feed pump. The conveyor is responsible for the precise dosing of the flakes into the continuous mixer (6).

2. Meanwhile, the Flaxseed Cutter (1) transforms flaxseeds into a homogeneous mass. This mass serves as the binding raw material for forming confectionery products.

3. The ground flaxseed mass is fed into the Syrup Preparation Mixer (2), which mixes the mass with other liquid ingredients. From there, the product enters the Discharge Tank (3), which ensures the supply of raw materials to the continuous mixer (6).

4. In the Continuous Mixer (6), the flaxseed mass and flakes are combined, allowing for the creation of a homogeneous mixture for further shaping.

5. The obtained mixture is delivered to the Shaping Head (7), where the product is pressed and formed into the required shape using the Press (8).

6. After pressing, the Additional Ingredients Feeder (9) adds the necessary amount of ingredients (e.g., nuts or other additives) on top.

7. Subsequently, the product is transferred to the Drying Complex (11), where

excess moisture is removed, ensuring the stability of the product.

8. After drying, the product passes through the Cooler (12), where its temperature is reduced to a safe level for further packaging.

9. In the cooled state, the product accumulates in the Centrifugal Feed Accumulator (13), which orients the product for further processing.

10. The final stage involves delivering the product to the Product Feeding System (14), from where it enters the Flow Pack (15) for automatic packaging into individual packages.

Thus, this line ensures a complete production cycle of confectionery products from flakes without sugar—from grinding and mixing raw materials to shaping, drying, cooling, and packaging the finished product. Figure 9 presents a photo of the finished products.

Figure 9 – Finished Products Produced from Raw Pumpkin

Results of the Study

During the conducted research, a machinery and equipment scheme and a technological process for the production of confectionery products without the use of sugar, wheat flour, and confectionery fats were developed. The research results confirm the effectiveness of the proposed approach in terms of technological feasibility, improvement of the nutritional value of the products, and economic viability.

1. Analysis of Alternative Raw Materials Properties

The analysis of the physicochemical and technological properties of the alternative raw materials showed:

- Low Glycemic Index: The selected raw materials, including millet flour, chickpea flour, flaxseed flour, and buckwheat flour, have a low or moderate GI, which promotes stable blood glucose levels after the consumption of products.
- High Protein and Fiber Content: Leguminous crops and pseudocereals are rich in plant-based protein with a complete amino acid profile and dietary fibers, which enhance the nutritional value of the products.
- Presence of Bioactive Compounds: A high content of antioxidants, polyphenols, and omega-3 fatty acids was identified, which positively affects consumers' health.
- Gluten-Free: Most of the alternative raw materials do not contain gluten, making the products suitable for individuals with celiac disease or gluten intolerance.

2. Development of the Technological Process

The proposed technological process, which includes raw material preparation, production of flakes in a tunnel dehydrator, shaping and drying of finished products, cooling, and packaging, demonstrated:

- Technological Efficiency: The use of a tunnel dehydrator with an applicator ensures uniform drying-baking of the raw materials at moderate temperatures (60–80°C), preserving bioactive compounds and improving the texture of the flakes.
- Quality of the Final Product: The obtained products have appealing organoleptic properties, including good texture, taste, and appearance, thanks to the use of flax-based binding syrup.
- Production Flexibility: The ability to combine different types of alternative raw materials allows for expanding the product range and adapting to market demands.

3. Design of the Machinery and Equipment Scheme

The developed machinery and equipment scheme demonstrated:

- Integration of Modern Equipment: The use of energy-efficient tunnel dehydrators, conveyor drying units, and automated shaping lines increases productivity and reduces energy costs.

- Automation of Processes: Reducing manual labor and increasing the accuracy of dosing and process parameter control improves product quality and reduces the risk of errors.

4. Compliance with Modern Market Trends

The research results indicate that the proposed technology aligns with current trends in the food industry:

- Demand for Healthy Products: Increasing consumer awareness of the impact of nutrition on health boosts the demand for products with a low glycemic index and gluten-free.
- Innovation: The use of alternative raw materials and the latest production technologies allows enterprises to stand out in the market and strengthen their competitive positions.
- Social Responsibility: The production of healthy confectionery products contributes to improving public health and aligns with the principles of sustainable development.

Conclusions

During the conducted research, a machinery and equipment scheme and a technological process for the production of confectionery products without the use of sugar, wheat flour, and confectionery fats were successfully developed, utilizing alternative raw materials with a low glycemic index. The research results confirmed the feasibility and effectiveness of the proposed approach from several key aspects.

1. Alternative Raw Materials as the Basis for Healthy Confectionery Products:

The analysis of the properties of alternative raw materials showed that the use of millet flour, chickpea flour, flaxseed flour, buckwheat flour, and other sources allows the creation of products with a low glycemic index, high protein content, and dietary fiber. This promotes a stable blood glucose level after consumption and enhances the nutritional value of the products.

2. Development of an Effective Technological Process:

The proposed technological process, which includes raw material preparation, production of flakes in a tunnel dehydrator, shaping and drying of finished products, cooling, and packaging, demonstrated:

- Technological Efficiency: The use of a tunnel dehydrator with an applicator ensures uniform drying-baking of the raw materials at moderate temperatures (60–80°C), preserving bioactive compounds and improving the texture of the flakes.
- Quality of the Final Product: The obtained products have appealing organoleptic properties, including good texture, taste, and appearance, thanks to the use of flax-based binding syrup.
- Production Flexibility: The ability to combine different types of alternative raw materials allows for expanding the product range and adapting to market demands.

3. Design of the Machinery and Equipment Scheme:

The developed production line scheme takes into account the specificities of processing alternative raw materials and integrates modern, energy-efficient equipment. The automation of processes and compliance with sanitary and hygienic standards increase production efficiency and ensure product safety.

4. Compliance with Modern Trends and Social Significance:

The development and production of confectionery products from alternative raw materials align with current trends in healthy eating and consumer demands for natural and beneficial products. This contributes to improving the quality of life of the population and reducing the risk of developing metabolic diseases.

5. Scientific Contribution and Opportunities for Further Research:

The research complements the scientific base regarding the use of alternative raw materials in the food industry and opens opportunities for further scientific developments in the field of healthy product manufacturing technologies.

Overall Conclusion:

The research results confirm that the development and implementation of a machinery and equipment scheme for the production of confectionery products without sugar, wheat flour, and confectionery fats are technically feasible and economically justified. The proposed technology allows for obtaining high-quality products with improved nutritional and functional characteristics that meet current market demands and contribute to the improvement of consumer health.

The implementation of this technology in industrial production will not only expand the range of healthy confectionery products but also enhance the competitiveness of food industry enterprises. This aligns with the principles of sustainable development and corporate social responsibility, emphasizing the importance of innovation in ensuring a healthy future for society.

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