Potential benefits of functional antianemic energy bars

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Abstract

Introduction. A multicomponent formulation of antianemic energy bars with improved nutritional and sensory properties has been developed.

Materials and methods. Model systems based on grains and nuts, dried fruits, honey and dietary iron supplements were used in the study. The chemical composition of the energy bars was analysed by colorimetric methods, liquid chromatography, and gas chromatography–mass spectrometry. Microbiological analysis was done according to generally accepted methods. Sensory analysis was carried out using a developed 10-point scale.

Results and discussion. Addition of dietary iron supplement in the amount 1.0 and 3.0 % to the recipe mixture increases the content of ash by 1.35 and 1.37 times; iron content by 1.27 and 1.29 times; the content of other minerals by 1.52±0.75%; vitamins by 1.36±0.41%; protein by 1.16 and 1.18 times; carbohydrates by 0.53±0.02%; and fat by 3.40±0.02%. At the same time, incorporation of dietary iron supplement in the amount 1.0 and 3.0 % improves the structure of bars by 1.06 and 1.08 times, the surface by 1.10 and 1.12 times, and consistency by 1.15 and 1.17 times; decreased the moisture content by 1.12–1.14 times, water activity by 1.13–1.15 times and the level of illumination, L* by 1.11 and 1.28 times, respectively; increases the index a* (degree of redness) by 6.78 and 8.56 times; index b* (degree of yellowness) by 2.14 and 3.16 times, respectively.

Texture profile analysis has proven that the addition of dietary iron supplement in the amount 1.0 and 3.0% increases the stiffness by 5.6 and 6.0%; adhesiveness by 1.86 and 2.76%; cohesiveness by 2.89 and 3.71%; elasticity (stability) by 1.54 and 2.30%; chewing rate by 1.76 and 2.62%; reduces elasticity by 1.86±0.21%, respectively.

The optimal mass fraction of dietary iron supplement was determined as 3.0%. Microscopic observations have proven the suppression of microbial contamination of the surface of prototypes of energy bars with the introduction of dietary iron supplement, 3.0%.

Conclusions. The multicomponent formulation of energy bars using dietary iron supplement has been developed. High functional and technological potential of the dietary iron supplement was shown, which gives opportunity to recommend it as a stabilizer, structure former, and improver of confectionery products.

Introduction

Food is a source of energy, the required amount of nutrients and biologically active substances: complete proteins, essential amino and fatty acids, vitamins, micro- and macroelements necessary for the normal functioning of the body. Currently, the main trend in the food industry is the creation of high-quality and safe products, so preservatives, synthetic additives and dyes are becoming increasingly unacceptable for consumers. In particular, the energy bars provide health benefits and also contain no traces of fertilizers and pesticides, which are often found in conventional foods (Iuliano et al., 2019).

In today's busy society, consumers are often looking for healthy and ready-to-eat food. Energy bars is a food in bar form designed to increase physical energy. This multi-component food system is a popular nutritional supplement due to its availability, compactness, convenience and ready-to-use, as well as a diverse, balanced composition of nutrients, high energy, biological and nutritional value (Fanari et al., 2023). There are a lot of energy bars types: high-carbohydrate (carbohydrate content more than 70%); high-protein (protein content from 5 to 20%); whole grains (oats, muesli, wheat, corn, rice), chocolate and multifruit bars (Boukid et al., 2022). Energetic bars supply the body with useful substances: proteins, fats, and carbohydrates to replenish energy, and in some cases with vitamins, minerals and antioxidants (Jabeen et al., 2020). It was foreseeable that the production and consumption of food products formulated for specific sporting activities would continually increase (Ivanov et al., 2021). Energy bars are recommended as food products for the nutrition of athletes, as they help strengthen the body and increase the effectiveness of training (Boukid et al., 2022; Fanari et al., 2023).

To produce multi-component energy bars with increased biological and nutritional value, mechanical grinding and mechanical activation of various raw materials are used. Raw ingredients of plant origin undergo technological, physicochemical and thermodynamic changes. Due to this, they acquire a light (crushed) structure and become more digestible by the body while maintaining their therapeutic and preventive properties.

In recent years, the trend towards consuming natural products has increased worldwide. Thus, sales of energy bars on the Great Britain market tripled for the period from 2017 to 2022, reaching 167 million euros, and in the US market it doubled, reaching 2919 million euros (Fanari et al., 2023). Numerous energy bar formulations have been developed to meet the energy and nutrient needs of different age groups and people with varying physical activity levels.

There are many studies aimed at enriching energy bars with various functional ingredients, such as soy products (Aramouni et al., 2011; Lobato et al., 2012), banana peel flour (Carvalho and Conti-Silva, 2018), pear, apple, and date fibres (Bchir et al., 2018), tempeh (Melo et al., 2020), bean flour (Maia et al., 2021), brewer's grain (Stelick et al., 2021), fish protein concentrate (Vitorino et al., 2020), fish oil (Nielsen and Jacobsen, 2009), milk proteins (Hogan et al., 2012), whey protein concentrate and bioactive ingredients (Szydłowska et al., 2017), and wine fermentation biomass (Borges et al., 2021). So, energy bar recipes consist primarily of cereals, legumes, fruits and nuts with the addition of natural enhancers, chocolate pieces or chocolate coating. To meet consumer demands for taste, texture and natural ingredients, innovative companies are using alternative protein sources, reviewing initial formulations, enriching them with essential and biologically active substances; adding unusual ingredients to create new functional products (Munir et al., 2019). However, there is practically no information on the production of energy bars with antianemic properties.

Iron deficiency is believed to be the leading cause of anemia, which affects more than 2,000 million people (World Health Organization, 2008). Recently, dietary iron supplements are considered to be appropriate food ingredients for the target population, fortifying the diet with the micronutrient iron (Banu and Mageswari, 2015; Evlash et al., 2021; Jarzębski et al., 2023; Hou et al., 2019; Riabchykov et al., 2022; Tang et al., 2015; Tsykhanovska et al., 2021; Tsykhanovska et al., 2022a, b; Xing et al., 2022). Therefore, creating new health products enriched with iron is relevant.

Dietary iron supplement (DIS) is a brown fine powder with a particle size of 50 microns having neutral taste and without smell. It is made from dietary blood of animal origin and contains heme iron in a reduced, easily digestible form Fe^{2+}. Iron supplement contains, %: protein, 75.0; fat, 2.5; carbohydrate, 20.0; organic acids, 0.4; cholesterol, 0.1; minerals, 1.5; and heme iron, 0.1 (Evlash et al., 2021). Hemovital contains all essential amino acids, as well as vitamins: A (retinol), E (α-tocopherol), C (ascorbic acid), B1 (thiamine), B2 (riboflavin), B3 (PP, niacin), B6 (pyridoxine), B9 (folic acid), B12 (cyanocobalamin) and minerals: Ca, K, Na, P, Mg, Cl, Cu, Se, Co, Zn, Mn, and I. Dietary iron supplement enriches the human body with complete protein and the trace element iron; it can be used as a natural dye; it improves the functional and technological properties, biological, nutritional value and quality indicators of finished food products.

The aim of the present research was to propose a multicomponent formulation of antianemic energy bar containing dietary iron supplement and study nutritional and sensory properties of enriched products.

Materials and methods

Materials

Sweet almond seeds, oat flakes, white flaxseeds, sunflower seeds, chia seeds, natural honey, nut butter, raisins, dried cherries, dried cranberries, and dietary iron supplement were used as raw materials for the production of energy bars.

Dietary iron supplement was introduced into the recipe mixture without changing the mass ratio of other recipe components of the product, at a dosage of 1.0 and 3.0%, respectively, 5.5 and 16.5 g per 550.0 g of the raw material mixture or 5.5 and 16.5 mg heme iron in mixture.

Since dietary iron supplement has color-forming properties, the use of a higher than 3.0% mass fraction of DIS by weight of the recipe mixture can adversely affect the color of the product, and in addition impart a pronounced off-flavor to the product. It should be noted that energy bar from 550.0 g of recipe mixture with addition of 3.0% DIS (or 16.5 mg of heme iron) covers the daily requirement of the human body for iron (on average 15–17 mg/day of total iron) (Latunde-Dada, 2024). That is, the product can be considered as an additional source of easily digestible iron in reduced form (Fe^{2+}) in the human diet, which is important in the modern nutritional structure of the population. Formulations for energy bars are shown in Table 1.

Production of energy bars

The traditional flow chart for the production of energy bars is shown in Figure 1.

Table 1

Formulations for energy bars with dietary iron supplement (DIS), g

Raw material	Control without DIS	Sample 1 with DIS, 1.0%	Sample 2 with DIS, 3.0%
Almond seeds	74.25±0.55	74.25±0.55	74.25±0.55
Oat flakes	148.50±5.50	148.50±5.50	148.50±5.50
White flaxseeds	19.80±1.10	19.80±1.10	19.80±1.10
Sunflower seeds	19.80±1.10	19.80±1.10	19.80±1.10
Chia seeds	19.80±1.10	19.80±1.10	19.80±1.10
Natural honey	79.75±5.50	79.75±5.50	79.75±5.50
Nut butter	56.10±5.50	56.10±5.50	56.10±5.50
Raisins	56.10±5.50	56.10±5.50	56.10±5.50
Dried cherries	56.10±5.50	56.10±5.50	56.10±5.50
Dried cranberries	56.10±5.50	56.10±5.50	56.10±5.50
Dietary iron supplement	–	5.50±0.02	16.50±0.02
The finished product output	586.30 ±36.30	591.80±36.32	602.80±36.32

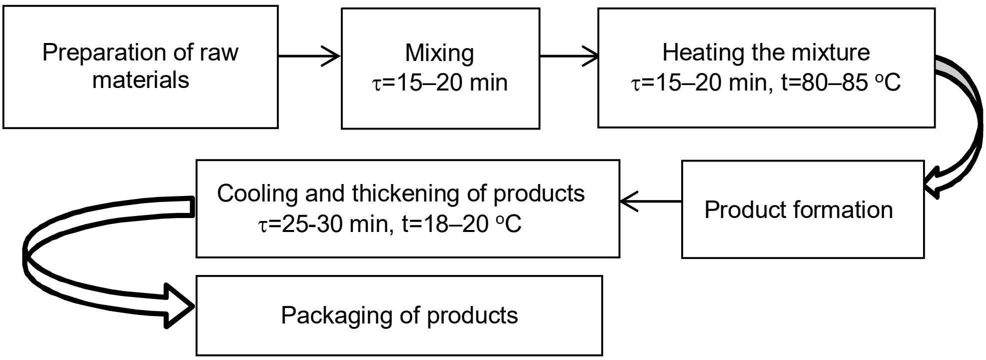

Figure 1. Flow chart for the production of energy bars

Oatmeal is crushed; almond, white flax, sunflower and chia seeds are sorted, cleaned of mechanical impurities, and crushed; dried fruits (raisins, cherries, cranberries) are washed, dried and cut into pieces; honey is heated to a temperature of t=45–50 ºC and mixed with nut butter; the dietary iron supplement is sifted, mixed with water GM=1:1 and kept for swelling at a temperature of 15–18 ºC for 35–40 min; combine the prepared components and mix thoroughly for 5–10 min. The mixture is heated to a temperature 80–85 ºC for 15–20 min; bars are formed by pouring the mass into a mold, cooled and kept for thickening at a temperature of 18–20 ºC for 20–25 min.

Methods

Physico-chemical analysis

Moisture content (W,%) was determined by the gravimetric method at a temperature of 105°C until the sample weight remained constant for 24 hours (Fanari et al., 2023).

Water activity (a_w) was measured at 25 °C using Aqualab 4TE (Decagon Devices Inc., Pullman, WA, USA) (ISO 18787, 2017).

Color was assessed using a CR-600d D65 colorimeter (Minolta Co., Osaka, Japan) by measuring CIE L*a*b parameters (Luo, 2015) at three points, ten strokes for each sample. The total color difference (ΔE) was calculated using CIE76 by formula (1), based on the Euclidean distances between colours in CIELab space:

$$\Delta E = \sqrt{(L_o - L)^2 + (a_o - a)^2 + (b_o - b)^2}\ , \qquad (1)$$

where L, a and b are parameters CIELab of sample, L_0, a_0 and b_0 are parameters CIELab of control.

Texture analysis. Texture was assessed using a TA.HDplusC Texture Analyser (Stable Microsystems, Surrey, UK) equipped with a 250 kg load cell; at a speed of 2 mm/s and a sample deformation of 75%. The samples were cut into 2x2 cm squares and kept for 2 hours at 20±2ºC and 45–50% relative humidity to standardize water absorption before testing. Next, 10 different parts were selected for 3 different batches, which were used to analyze the textural characteristics: hardness, adhesiveness, cohesiveness, elasticity, chewiness, and springiness according to the method (Szczesniak, 2002). PTA is a double compression test known as the "two bite test", which simulates chewing with the mouth. The test results are displayed as a graph of force (compression or tension) as a function of time or distance: Hardness, F1(g) is maximum value of force (tension); adhesiveness, A3 (g/s) is negative area of the graph; cohesiveness, A2/A1 (g) is ratio of areas under two peaks; elasticity, A5/A4 (g) is ratio of areas under the first erysipelas; elasticity, T2/T1 (g) is ratio of the time of formation of two peaks; chewing, F1× (A2/A1)2 (%) is stickiness × cohesiveness.

Nutrient analysis. The mass fraction of fat was determined using an automatic installation for solid-hour extraction SOXTHERM SOX414 (Gerhardt, Germany) and using a Minispec MQ-20 NMR relaxometer (Bruker BioSpin GmbH, Germany) in accordance to the method (Gianferri et al., 20).

The biological value of the fatty acid complex was studied by experimental determination of the fatty acid composition by gas chromatography-mass spectrometry (GC-MS) using a Clarus 600 T GC-MS device (PerkinElmer, USA) and the methodology given in (Dulf, 2012; Petraru et al., 2021). The protein mass fraction was determined using the N2/DKL8 protein quantitative identification system (Velp Scientifica, Italy) according to the method (Krasina and Tarasenko, 2016).

The biological value of the protein complex was studied by experimental determination of the amino acid composition using the capillary electrophoresis system "Carel-105M" with a spectrophotometric detector (Lumex, Ukraine) according to the method given in (Krasina and Tarasenko, 2016), and using liquid chromatography (Dionex ICS-3000, USA) with an electrochemical detector (Electrochemical Detector Cell) according to the method given in (Oseyko et al., 2020; Petraru et al., 2021; Rosa et al., 2009).

The mass fraction of fiber was determined using a FIBRETHERM FT12 fiber analysis unit (Gerhardt, Germany) according to the user instructions and methods given in (Krasina and Tarasenko, 2016).

Organic acids were determined by high-performance liquid chromatography of an HPLC system on an LC-20AD instrument (Schimadzu, Kyoto, Japan) with a SIL-20A sampler, a CTO-20AC column oven, a Phenomenex Luna® Omega 3 µm SUGAR 1 column and a RID-10A diode detector according to methodology (Pauliuc et al., 2021).

Content of vitamins sis was determined using an Agilent 1100 high-performance four-channel liquid chromatograph (Agilent Technologies, USA) combined with a diode array detector and mass spectrometry according to the method (Katsa et al., 2021; Sim et al., 2016).

The mineral composition was determined by mass spectroscopic studies (mass spectrometer Agilent 7500 S, USA) in accordance with the methodology given in (Sinkovic and Kolmanic, 2021).

Sensory analysis

Sensory analysis of energy bars was carried out in accordance with the methodology (Fanari et al., 2023; Jabeen et al., 2020).

A tasting commission of 15 tasters who had experience in sensory analysis of various food products for more than 2 years, based on the hedonic scale, determined the following indicators: color: 3, max score, weight coefficient, 0.3; smell: 1, max score, weight coefficient, 0.1; taste 1, max score, weight coefficient, 0.1; surface 1, max score, weight coefficient, 0.1; texture 1, max score, weight coefficient, 0.1; consistency 3, max score, weight factor, 0.3. Overall score, 10, weight coefficient, 1.0, with: 9.5–10.0, excellent; 9.4–9.0, very good; 8.5–8.9, good; 8.0–8.4, satisfactory; less than 8.4 is unsatisfactory. The sample size was 3-4 g for each test bar. Before each subsequent test, drinking water was offered as a mouth rinse.

Microbiological analysis

To conduct microbiological studies, the following media were used: nutrient agar was used for plate counting of the total number of microorganisms, namely the number of mesophilic aerobic and facultative anaerobic microorganisms (MAFAM); potato dextrose agar was used for counting yeasts and molds; Salmonella Shigella Agar was used for the determination of *Salmonella* spp.; Endo Agar was used for determination of the presence of *Escherichia coli* bacteria; Kessler medium was used for determining of colliter. Microbiological analysis was carried out according to the conventional methods for microbiological analysis of food products (Erkmen, 2022; Hasell et al., 2003; Olunlade et al., 2013).

Statistical analysis

Statistical analysis of the experiment results was carried out using Statistica 6.0, Microsoft Office Excel 2007 and Mathcad. Data were expressed as mean ± standard deviation to define three measurements.

Results and discussion

The chemical composition of the main raw ingredients was experimentally determined (Table 2).

Almond seeds contain, %: proteins, 18.6; carbohydrates, 21.6; fat, 49.9; as well as 8 water-soluble and 1 fat-soluble vitamins; 5 macroelements and 4 microelements. It is important to note that almond protein contains a high amount of arginine, 11.2%, and is highly digestible. Almonds contain a complex of unsaturated fatty acids, namely: oleic acid, 78.0%, linoleic acid, 21.5%, linolenic acid, 9.8%, and palmitoleic acid, 1.5%. Almond fat is highly resistant to oxidation due to the content of antioxidants (phytosterols, vitamin E), which is consistent with the data from other sources (Franklin et al., 2019; Tomishima et al., 2022; Zhu et al., 2015). The chemical composition of almond seeds provides it with natural biological and nutritional value, health benefits including lowering cholesterol, improving cardiovascular health and reducing blood pressure.

Oat flakes contain protein, carbohydrate, fatty acid and vitamin-mineral complexes, namely nine vitamins (B1, B2, B4, B5, B4, B6, B9, C, PP, E) and nine minerals (K, Na, Ca, Mg, P, Fe, Zn, Cu, Se). The absence of gluten makes all cereals friendly to people with celiac disease. The absence of gluten makes oat flakes friendly to people with celiac disease. Oat flakes is a source of many compounds having high antioxidant capacity, such as flavonoids, phenolic acids, and vitamin E (Hu, 2014; Zhang et al., 2021).

Flaxseeds contain a significant amount of fat (45%), which has a high content of linolenic acid, which provides the fat with the ability to dry quickly, forming a thin, smooth and shiny film. Flax seeds are a "source of protein", accounting for 22.5% of the total seed mass. It should be noted that there is a fairly high content of vitamins B4 (78.7 mg/100 g), B9 (87.0 μg/100 g), E (19.9 mg/100 g) and minerals such as potassium, magnesium, phosphorus, iron, selenium. Flaxseeds contain a high amount of α-linolenic acid (ω-3), and have low ratio ω-6/ω-3, 0.27, which makes them the perfect material to be used for creating functional products (Stabnikova and Paredes-Lopez, 2024). The presence of natural antioxidants (α-tocopherol, chlorogenic acid) helps combat oxidative stress, which contributes to improved overall health (Ayelign et al., 2016; Bernacchia et al., 2014).

Sunflower seeds have a very diverse chemical composition and include different classes of compounds that are beneficial to human health (Tsykhanovska et al., 2023). It has been determined that sunflower seeds contain 20.8% protein, rich in amino acids, including essential ones. The seeds contain 51.5% fat, which includes saturated fatty acids, 10.24%; monounsaturated fatty acids, 37.82%; polyunsaturated fatty acids, 51.94%. Vitamins found in sunflower seeds are: C, E, group B, but the largest amount is for B3, 8.3 mg/100 g; B9, 227.0 μg/100 g, and E, 35.2 mg/100 g; minerals, among which the following are potassium, 645.0 mg/100 g, magnesium, 325.0 mg/100 g, phosphorus, 660.0 mg/100 g, iron, 5.3 mg/100 g, and selenium, 53.0 μg/100 g (Table 2). This is consistent with the experimental data of other scientists (Bashir et al., 2015; González-Pérez et al., 2017; Petraru et al., 2021).

Chia seeds have a high protein content, 21.8%, carbohydrates, 41.0% and fat, 31.2%. The main components of chia seed fats are polyunsaturated fatty acids, in particular α-linolenic and linoleic acids. The ratio between ω-6 and ω-3 fatty acids is 0.33 (Stabnikova and Paredes-Lopez, 2024). In addition, chia seeds contain minerals such as calcium, phosphorus, potassium, magnesium, iron, selenium; vitamins B1, B2, B3, B6, B9; a large number of natural antioxidants such as tocopherols, phytosterols, carotenoids and polyphenolic compounds. The findings are consistent with the results of other researchers (Imran et al., 2016; Kulczyński et al., 2019).

Table 2

Chemical composition of raw materials

Compounds	Sweet almond	Oat flakes	White flaxseeds	Sunflower seeds	Chia seeds	Natural honey	Peanut butter	Raisins	Dried cherries	Dried cran-berries
Nutrients, g/100 g										
Protein	18.6 ±0.50	15.48 ±0.46	22.5 ±0.6	20.8 ±0.62	21.8 ±0.65	0.07 ±0.002	23.2 ±0.7	3.4 ±0.1	1.5 ±0.04	0.2 ±0.006
Carbo-hydrate	21.6 ±0.65	69.12 ±2.07	25.1 ±0.75	20.0 ±0.60	41.0 ±1.23	96.0 ±2.88	21.15 ±0.6	79.5 ±2.4	76.5 ±2.30	82.8 ±2.50
Fat	49.9 ±1.50	8.78 ±0.26	45 ±1.35	51.5 ±1.54	31.2 ±0.94	n.d	51.4 ±1.5	1.35 ±0.04	0.2 ±0.01	1.1 ±0.03
Vitamins, mg/100 g										
B_1	0.17 ±0.01	1.17 ±0.03	1.6 ±0.05	1.5 ±0.04	0.48 ±0.01	5.2 ±0.15	0.6 ±0.02	n.d	0.02 ±0.00	0.02 ±0.00
B_2	0.62 ±0.02	0.22 ±0.01	0.2 ±0.01	0.4 ±0.01	0.17 ±0.01	45 ±1.35	0.1 ±0.01	0.2 ±0.006	0.02 ±0.00	0.02 ±0.00
B_4	0.22 ±0.01	40.4 ±1.21	78.7 ±2.36	55.1 ±1.65	n.d*	2.2 ±0.06	63.0 ±1.89	11.1 ±0.33	4.8 ±0.14	8.3 ±0.25
B_5	0.78 ±0.02	1.49 ±0.04	1.0 ±0.03	1.1 ±0.03	n.d	0.1 ±0.01	1.1 ±0.03	0.1 ±0.003	0.06 ±0.00	0.01 ±0.00
B_6	0.82 ±0.02	0.17 ±0.01	0.5 ±0.01	1.3 ±0.04	0.180 ±0.005	128 ±3.80	0.3 ±0.01	0.3 ±0.01	0.04 ±0.00	0.02 ±0.001
PP(B_3)	4.8 ±0.14	0.934 ±0.03	3.1 ±0.09	8.3 ±0.25	6.95 ±0.21	76 ±2.28	13.1 ±0.40	1.1 ±0.03	0.4 ±0.01	0.5 ±0.015
C	8.5 ±0.25	0.01 ±0.00	0.6 ±0.02	1.4 ±0.04	1.60 ±0.05	0.5 ±0.01	n.d	3.2 ±0.10	12.4 ±0.40	0.2 ±0.001
E	23.5 ±0.70	1.01 ±0.03	19.9 ±0.6	35.2 ±1.05	1.48 ±0.04	n.d	9.1 ±0.30	0.1 ±0.00	0.24 ±0.01	2.1 ±0.06
B_9, µg /100 g	44.1 ±1.32	52 ±1.56	87.0 ±2.6	227.0 ±6.8	0.15 ±0.00	2.0 ±0.06	87.0 ±2.61	3.0 ±0.10	4.8 ±0.14	0.5 ±0.015
Minerals, mg/100 g										
K	733.1 ±21.9	566 ±17.00	800.1 ±24.0	645.0 ±19.3	420.8 ±12.6	410.0 ±12.3	558.0 ±16.7	746.0 ±22.4	204.8 ±6.14	49.0 ±1.47
Na	1.0 ±0.03	2.0 ±0.06	30.0 ±0.90	9.0 ±0.27	16.1 ±0.5	24.6 ±0.74	426.0 ±12.7	12.4 ±0.4	16.0 ±0.50	5.0 ±0.15
Ca	269.0 ±8.07	58 ±1.74	267.0 ±8.01	78.0 ±2.34	594.0 ±17.8	26.5 ±0.8	47.24 ±1.4	53.3 ±1.6	29.6 ±0.80	9.0 ±0.27
Mg	270.0 ±8.10	235 ±7.05	400.2 ±12.0	325.0 ±9.75	296.4 ±8.8	6.82 ±0.2	168.0 ±5.04	35.7 ±1.07	20.8 ±0.60	4.0 ±0.12
P	481.0 ±14.4	734 ±22.02	667.0 ±20.01	660.0 ±19.8	720.0 ±21.6	38.3 ±1.15	334.6 ±10.0	115.4 ±3.5	24.0 ±0.70	8.0 ±0.24
Fe	3.7 ±0.11	5.41 ±0.16	4.8 ±0.14	5.3 ±0.16	7.1 ±0.2	2.3 ±0.07	1.4 ±0.04	1.8 ±0.05	0.4 ±0.01	0.4 ±0.01
Zn	3.1 ±0.09	3.11 ±0.09	4.0 ±0.12	5.0 ±0.15	4.6 ±0.14	0.3 ±0.01	2.4 ±0.07	0.3 ±0.01	0.12 ±0.00	0.1 ±0.00
Cu, µg/100 g	1.0 ±0.03	403 ±12.09	1.2 ±0.04	1.8 ±0.05	1.09 ±0.03	0.01 ±0.0003	0.4 ±0.01	0.4 ±0.01	80.4 ±2.40	0.1 ±0.00
Se, µg/100 g	4.1 ±0.12	45.2 ±1.35	25.4 ±0.76	53.0 ±1.59	54.6 ±1.64	0.8 ±0.024	4.1 ±0.12	0.7 ±0.02	0.08 ±0.00	0.6 ±0.02

*n.d-non-detects

Nut (peanut) butter contains 23.2% highly digestible proteins, 51.4% fats and 21.15% carbohydrates. Nut butter is rich in vitamins, especially B vitamins, namely: B3, 13.1 mg/100 g, B4, 63.0 mg/100 g, B5, 1.1 mg/100 g. Nut butter contains a fairly high amount of tocopherols, 9.1 mg/100 g; minerals: potassium, sodium, phosphorus, zinc, selenium and bioactive compounds that can exhibit protective effects against cardiovascular diseases, cancer, diabetes, osteoporosis and other degenerative diseases (Bonku et al., 2020; Shibli et al., 2019).

Natural honey contains a significant amount, g/100 g, of: carbohydrates, 96.0, mainly fructose, 2.8, glucose, 27.7, and sucrose, 0.5. Honey contains vitamins, especially vitamins of B-group, among which B1, 5.2 mg/100 g, B2, 45 mg/100 g, B3, 76 mg/100 g, and B6, 128 mg/100 g, are predominate. Honey contains macroelements (potassium, calcium and sodium), and microelements (iron, copper, and zinc), which perform a fundamental function in biological systems: maintaining normal physiological reactions, inducing general metabolism, influencing the circulatory system and reproduction, as well as catalysts for various biochemical reactions. Honey contains only trace amounts of protein, which agrees with the data of others (Bogdanov et al., 2008; Tafere, 2021).

Raisins contain small amounts of protein, 3.4%, and fat, 1.35%. Carbohydrates, 79.5%, which are represented by fructose, 24.3 g/100 g, glucose, 18.2 g/100 g, and small amounts of sucrose, 0.85 g/100 g, are dominated compounds in the honey composition. Raisins contain vitamins of B-group, vitamins C and E; minerals (potassium, calcium, iron, magnesium, and phosphorus). Raisins contain valuable pectin, 2.4%, and dietary fiber, 0.91%. Pectin is practically not absorbed by the human digestive system. It plays a role of adsorbent capable of binding heavy metals, radionuclides and excess cholesterol and removing them from the body. It has antimicrobial and anti-inflammatory agents, helps reduce cholesterol and blood sugar levels, and improves digestive function (Ghrairi et al., 2013; Maki et al., 2023).

Cherry fruits contain a small amount of protein, 1.5%, and fat, 0.2%. Identified carbohydrates make up to 76.5%, represented by fructose, 22.3%, glucose, 14.4%, and sorbitol, 8.9%. They also contain dietary fiber, 0.86%; organic acids (malic, 8.0%, succinic, 1.2%, salicylic, 1.8%, citric acid, 6.0%); minerals, vitamins, namely thiamine, ascorbic acid, and nicotinic acid. Cherries also contain tannins, coloring substances and antioxidants. Consumption of cherry fruits improves appetite, regulates intestinal activity, and increases the digestibility of fats and proteins (Cairone et al., 2023; Serradilla et al., 2017; Sokół-Łętowska et al., 2020).

Cranberry fruits contain a small amount of proteins, 0.2%, and fats, 1.1%. The amount of carbohydrates is 82.8%, which includes fructose, 16.7%, glucose, 8.44%, sucrose, 1.6%, dietary fiber, 0.8%. Cranberry fruits contain vitamins B group, vitamins C and E, and antioxidants. There is a large amount of minerals present, namely potassium, phosphorus, magnesium, calcium, iron, zinc, copper, which is consistent with the data of other researchers (Jurikova et al., 2019; Nemzer et al., 2022).

Dietary iron supplement provides the human body with complete protein and can be used as a natural brown dye. DIS contains 75% of protein and 0.1% heme iron (Figure 2). The use of such a supplement allows to enrich diet with iron and protein, improves the functional and technological properties and quality indicators of finished confectionery products.

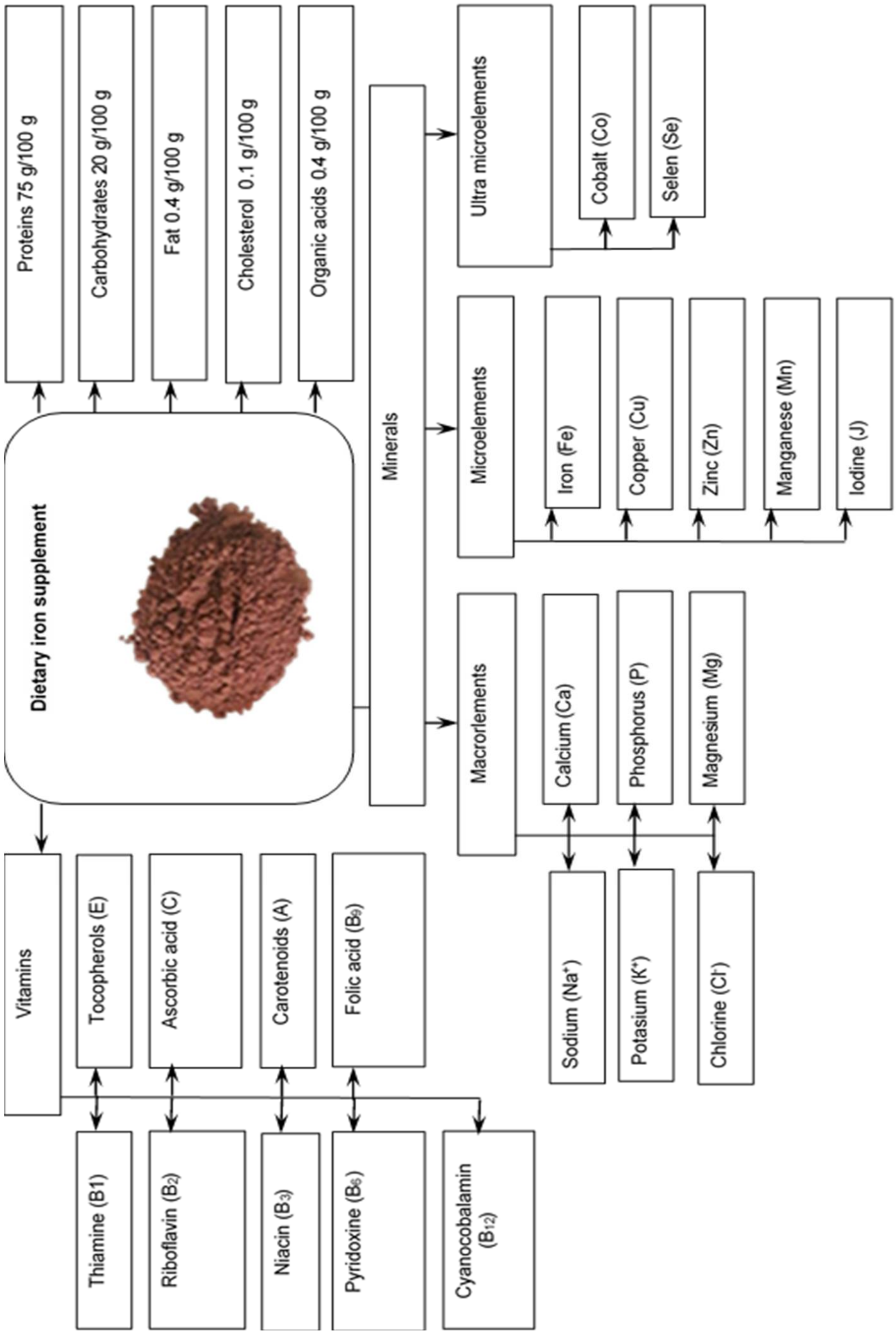

Figure 2. Nutrient profile of dietary iron supplement

To determine the rational amount of dietary iron supplement in the formulation of energy bars, a sensory analysis of samples was carried out. The results are shown in Table 3, Table 4, and Figure 3.

Table 3

Sensory analysis of energy bars with dietary iron supplement (DIS)

Sample	Structure	Consistency	Taste	Smell	Color	Surface
Control	Fine crystalline uniform mass, with barely noticeable small hard slices of components	Semi-solid, but not dense, with low viscosity	Pleasant, with pronounced taste of dried fruits	Pleasant, with pronounced dried fruit aroma	Brown, homogeneous in mass	Non-sticky, homogeneous mass with small, isolated cracks
Sample 1 with DIS, 1%	Fine crystalline, with even distribution components throughout the mass	Semi-solid, with uniform density	Pleasant, with pronounced taste of dried fruits	Pleasant, with pronounced dried fruit aroma	Brown, homogeneous in mass	Non-sticky, homogeneous mass without cracks
Sample 2 with DIS, 3%	Fine crystalline, with even distribution components throughout the mass	Semi-solid, with uniform density	Pleasant, with pronounced taste of dried fruits	Pleasant, with pronounced dried fruit aroma	Brown, homogeneous in mass	Non-sticky, homogeneous mass without cracks

Energy bars with dietary iron supplement added to the recipe mixture in amounts of 1.0% and 3.0% had the same organoleptic properties (surface, taste, smell and color) as control. However, the structure, surface and consistency of the bars with DIS were improved compared to control.

Addition of DIS, 3.0% (w/w), allowed to introduce 16.5 mg of heme iron in 550.0 g of the product that practically satisfies the daily need of the human body for iron (on average 15–17 mg/day of total iron). Thus, the most acceptable are energy bars with introduction of dietary iron supplement in the amount 3.0% by weight in the recipe mixture.

Results of sensory assessment of the energy bars in points are shown in Table 4 and Figure 3.

Energy bars prepared with addition of dietary iron supplement in the amounts 1.0% and 3.0% by weight of the recipe mixture had the highest score of 9.77 ± 0.22. The data obtained confirm the results of the sensory analysis indicated in Table 3. That is, compared to control, the following were improved: structure by 1.07 times, surface by 1.11 times and consistency by 1.16 times; the color becomes somewhat saturated; the total score increases by 1.07 times.

Table 4

Sensory assessment of the energy bars with dietary iron supplement (DIS) in points

Parameters	Control	Sample 1 with DIS, 1.0%	Sample 2 with DIS, 3.0%
Structure	0.92±0.02	0.98±0.02	0.98±0.02
Smell	0.95±0.03	0.95±0.03	0.95±0.03
Surface	0.88±0.02	0.98±0.02	0.98±0.02
Color	2.90±0.06	2.94±0.06	2.94±0.06
Consistency	2.55±0.05	2.97±0.07	2.97±0.07
Taste	0.95±0.03	0.95±0.03	0.95±0.03
Overall score	9.15±0.21	9.77±0.22	9.77±0.22

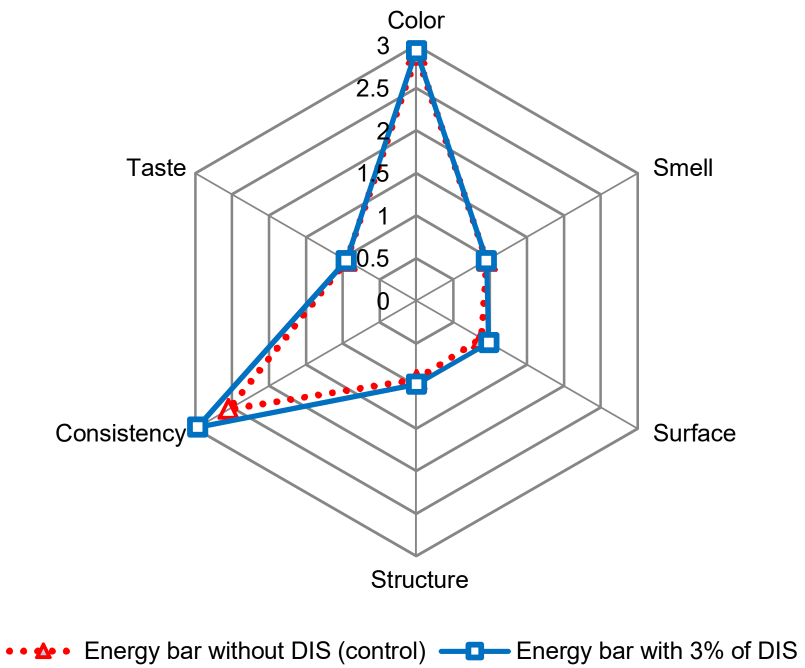

Figure 3. Sensory assessment of the energy bars with dietary iron supplement (DIS)

Thus, the recommended amount of dietary iron supplement is 3.0% by weight in the recipe mixture of energy bars.

Analysis of the chemical composition of energy bars shows an improvement in the biological value of the product added with DIS compared to control (Table 5).

Table 5

Chemical composition of energy bars with dietary iron supplement (DIS)

Compounds	Control	Sample 2 with DIS, 3,0%	Compounds	Control	Sample 2 with DIS, 3.0%
Macronutrients, g/100 g dry weight			P	191.08±3.73	191.66±3.74
Water	9.56±0.08	8.43±0.04	I	0.009±0.0	0.012±0.0
Proteins	9.61±0.28	11.28±0.31	Fe	59.08±1.69	75.78±1.89
Fat	8.30±0.24	8.58±0.24	**Vitamins, g/100 g dry weight**		
Carbohydrate	68.22±1.06	70.62±1.07	A	2.92±0.06	2.96±0.07
Fiber	3.97±0.09	3.97±0.09	E	1.51±0.04	1.54±0.04
Organic acids	0.42±0.01	0.46±0.01	C	0.82±0.02	0.85±0.02
Ash	2.14±0.05	2.96±0.06	B_1	0.41±0.01	0.44±0.01
Minerals, g/100 g dry weight			B_2	0.31±0.01	0.33±0.01
Na	55.04±1.68	56.26±1.71	B_3 (PP)	0.62±0.01	0.65±0.02
K	465.0±13.0	468.0±13.0	B_6	1.60±0.04	1.64±0.04
Ca	86.12±2.18	87.65±2.16	B_9	0.52±0.01	0.54±0.01
Mg	99.14±2.34	101.34±2.42	B_{12}	0.82±0.02	0.85±0.02

Addition of dietary iron supplement, 3.0% (w/w) improves the mineral-vitamin and protein-carbohydrate compositions compared to control, namely, the Fe content increases by 1.28 times; other micro- and macroelements by 1.52±0.75%; vitamins by 1.36±0.41%; ash by 1.38 times; protein by 1.17 times; carbohydrates by 0.55%; as well as fat by 3.42%. This is due to the rich chemical composition of dietary iron supplement. The water absorption capacity of highly dispersed powdered DIS reduces the moisture content by 1.13 times compared to control, which helps to improve the microbiological characteristics of the finished product.

It has been shown that the main supplier of energy in energy bars with DIS is carbohydrates (Table 6).

Table 6

Nutritional value of energy bars with dietary iron supplement (DIS)

Compounds	Control	Sample 2 with DIS, 3.0%
Protein, g/100 g energy bar	9.61±0.28	11.28±0.31
Fat, g/100 g energy bar	8.30±0.24	8.58±0.24
Carbohydrates, g/100 g energy bar	72.19±1.16	74.59±1.17
Approximate calorie content, Kcal/100 g	401.90	420.70
Calories from carbohydrates, %	288.76	298.36

Energy bar added with dietary iron supplement was enriched in comparison with control with complete proteins of animal origin containing a balanced composition of essential amino acids. Consequently, the addition of DIS in an amount of 3.0% by weight of the recipe mixture improves the nutritional value and consumer properties of the finished product.

Analysis of the physicochemical characteristics of energy bars shows that the introduction of 1.0% and 3.0% brown dietary iron supplements into the recipe compared to control reduces the lighting level L* by 1.11 and 1.28 times, respectively; significantly increases: index a* (degree of redness) by 6.78 and 8.56 times, respectively; indicator b* (degree of yellowness) 2.14 and 3.16 times, respectively (Table 7).

Table 7

Physicochemical characteristics of energy bars with dietary iron supplement (DIS)

Samples	L*	a*	b*	ΔE	M, %	a_w
Control	74.93±0.82	0.68±0.02	17.58±0.12	0.00	9.56±0.04	0.476±0.002
DIS, 1.0%	67.55±0.51	4.61±0.12	37.68±0.21	23.45±0.51	8.39±0.03	0.416±0.001
DIS, 3.0%	58.46±0.42	5.82±0.14	55.52±0.36	29.82±0.57	8.43±0.03	0.419±0.001

These color changes may be due to the high content of hemoglobin and myoglobin (red color) and bilirubin (yellow color pigment) in DIS (dietary blood product). The value of the “color difference”, ΔE, in the samples with DIS was above 7.0, that is, the color of the bars is considered visible to the human eye, and DIS has color-forming ability. The color changes are more pronounced in the energy bar containing 3.0% of dietary iron supplements.

It has been found that the use of addition of dietary iron supplements, 1.0% and 3.0%, reduced moisture content by 1.13 times compared to control. It is related to the hydration capacity of the protein-carbohydrate complex of highly dispersed DIS powder. This effect on moisture content was also influenced by the values of water activity, a_w, which were lower in bars with DIS by approximately 1.14 times compared to control. Similar results for moisture content and water activity were observed by other authors for confectionery products with the addition of highly dispersed food additives (Batista et al., 2019; Fanari et al., 2023). The crispness of the product is highly dependent on the water content and/or a_w values. When they decrease, food products become harder and crispier. In any case, taking into account the influence of the mass fraction of DIS on the consumer properties of the finished product in this study, the rational mass fraction of DIS is 3.0% (w/w) of the mass of the recipe mixture. This amount of DIS is not capable of causing negative changes in the texture of the energy bars (Table 8).

Table 8

Texture profile of energy bars with dietary iron supplement (DIS)

Samples	Hardness, g	Adhesiveness, g/s	Cohesiveness, g	Elasticity, g	Chewing, %	Springiness, g
Control	792.3 ±2.1	-86.42 ±0.33	0.242 ±0.001	0.482 ±0.012	74.26 ±1.13	0.052 ±0.001
DIS, 1.0%	836.5 ±2.2	-88.03 ±0.33	0.249 ±0.001	0.473 ±0.012	76.12 ±1.13	0.060 ±0.001
DIS, 3.0%	843.8 ±2.2	-88.81 ±0.33	0.255 ±0.001	0.462 ±0.012	76.88 ±1.13	0.064 ±0.001

The texture of energy bars is an important factor for consumer acceptance beyond appearance and taste. Texture is inextricably linked to the structure of the product at the micro- and macro-levels, and is strongly influenced by the interaction of food biopolymers: proteins, polysaccharides and lipids. In addition, the components of the product must be released from the food matrix to reach the appropriate taste buds. This process is closely related to the way in which the food structure breaks down in the mouth, both in terms of the initial texture of the food product and the change in its texture during chewing. The hardness of test samples with 1.0% and 3.0% of DIS increases compared to control by 5.6% and 6.0%, respectively, due to lower moisture content, increased protein content and the Maillard reaction, which induces polymerization and interaction of protein molecules and polysaccharides, helping to strengthen the structure. The added amounts of DIS ("protein source") was not sufficient to achieve an undesired hardening according to Regulation of the European Parliament and of the Council (EC) No. 1924/2006, taking into account also the high content of carbohydrates present in the dietary iron supplement. A decrease in hardness by 5.8±0.2% and an increase in elasticity by 1.86±0.21% of control bars is influenced by a higher moisture content and higher water activity, which promotes the action of H_2O as a retarder of cross-linking of sugars and proteins.

Addition of 1.0% and 3.0% DIS increases adhesiveness by 1.86% and 2.76%, respectively, due to the hydration, structure-forming and stabilizing ability of the increased amount of proteins and the migration of moisture from the outer layers to the inner layers , which helps strengthen the adhesion of the product to the surface; cohesiveness by 2.89% and 3.71%, respectively, due to cross-linking between biopolymer molecules: proteins, carbohydrates, lipids and the formation of a stable spatial food matrix.

Higher adhesiveness and cohesiveness of the energy bars added with 1.0% and 3.0% DIS compared to control resulted in an improvement in the chewing ability of the product and an increase in the chewing index by 1.76% and 2.62%, respectively.

Addition of 1.0% and 3.0% DIS increases elasticity (stability) by 1.54% and 2.30%, respectively. This is due to the strengthening and stabilization of the structure of the product through electrostatic intermolecular interactions of biopolymer ingredients: hydrophobic and polar sections of macromolecules, ionic and ionized groups.

Therefore, the results of physicochemical and structural-mechanical studies confirmed that the recommended mass fraction of DIS is 3.0% by weight of the recipe mixture.

The results of the influence of DIS on microbial contamination of the surface of energy bars initial after production and after storage for 75 days at relative air humidity 75±2% are shown in Table 9.

Table 9

Microbiological analysis of energy bars

Characteristics	Standard**	Energy bars	
		Control	with DIS, 3.0%
MAFAM, CFU*/g, initial / after 75 d	$\leq 1.0\times10^3$	n.d.*** / 2.0×10^2	n.d. / 1.0×10^2
Yeasts, CFU/g, initial / after 75 d	≤50	n.d. / 6.0	n.d. / 4.0
Coliform bacteria, initial / after 75 d	n.a.**** in 0.1 g	n.d. / n.d.	n.d.
Pathogens (*Salmonella*), initial / after 75 d	n.a. in 25.0 g	n.d. / n.d.	n.d.
Molds, CFU/g, initial / after 75 d	≤ 50	n.d. / 6.0	n.d. / 3.0

*CFU, colony formed units;
**The standards are established by ISO 16140:2016 Microbiology of the food chain and European Food Safety Authority, 2021;
***n.d., not detected,
****n.a., not allowed

Microbiological analysis of energy bars with DIS, 3%, showed that they correspond to regulatory documentation. In addition, the introduction of 3.0% DIS suppresses contamination of the surface of energy bars: the number of mesophilic aerobic and facultative anaerobic microorganisms (MAFAM) was 2 times lower compared to control, yeasts by 1.5 times, molds by 2.0 times after storage at air humidity 75±2% for 75 days. This is due to the water-absorbing and structure-forming effect of the dietary iron supplement, which helps reduce the moisture content in the product.

Conclusions

The nutrient composition of the raw materials of multicomponent antianemic energy bars and the finished product has been studied. The results of a study of the influence of dietary iron supplements on the quality indicators of antianemic energy bars showed that the addition of 1.0 and 3.0 % (w/w) dietary iron supplements has a positive effect on the biological and nutritional value; sensory, physico-chemical, structural-mechanical and microbiological characteristics of the finished product, in particular:

1. Addition of 1.0 and 3.0% dietary iron supplement improved compared to control: biological and nutritional value of the finished product, namely the content increases: Fe by 1.27–1.29 times; other micro- and macroelements by 1.52±0.75%; vitamins by 1.36±0.41%; ash by 1.37–1.39 times; protein by 1.16–1.18 times; carbohydrates by 0.53±0.02%; fat by 3.40±0.02%; structure by 1.06–1.08 times, surface by 1.10–1.12 times and consistency by 1.15–1.17 times; the color becomes somewhat saturated; the total score increases by 1.07 times, respectively.
2. Physicochemical studies showed that the addition of 1.0–3.0% dietary iron supplement compared to control: reduces moisture content by 1.12–1.14 times and water activity by 1.13–1.15 times; reduces the lighting level, L*, by 1.11 and 1.28 times, respectively; significantly increases: index a* (degree of redness) by 6.78 and 8.56 times, respectively; indicator b* (degree of yellowness) by 2.14 and 3.16 times, respectively.
3. Texture profile analysis proved that the addition of 1.0% and 3.0% dietary iron supplement compared to control: increases hardness by 5.6% and 6.0%; adhesiveness by 1.86% and 2.76%; cohesiveness by 2.89% and 3.71%; elasticity (stability) by 1.54% and 2.30%; chewing rate by 1.76% and 2.62; reduces elasticity by 1.86±0.21%, respectively.
4. The recommended amount of dietary iron supplements was determined as 3.0% of the weight of the recipe mixture.
5. The decrease of microbial contamination of the surface of energy bars with the dietary iron supplement, 3.0%, has been proven.
6. The conducted studies showed a high functional and technological potential of the dietary iron supplement, which could be recommended as a stabilizer and improver of structure of food items, in particular confectionery products.

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