Quality indicators of multicomponent dairy-vegetable concentrates

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Abstract

Introduction. Effective milk processing with optimal use of its components, search for new sources of protein, and partial replacement of proteins of animal origin with vegetable ones could be considered as the ways to solve the problem of protein deficiency.

Materials and methods. The dairy-vegetable concentrate was obtained from the dairy-vegetable mixture by the thermal acid precipitation of proteins. The yield (mass) was determined by the weighing method. The mass fraction of moisture was determined by the thermogravimetric method. Determination of water activity of model samples of concentrates was carried out on a hygrometer.

Results and discussion. The results of determining the yield of concentrates, their physico-chemical and sensory indicators confirmed the possibility of partial replacement of skimmed milk with whey-plant suspension with *Arachis hypogaea* fruit at the ratio of 7:3 in mixtures for thermal acid precipitation of proteins. Dairy-vegetable concentrates had a more developed spatial configuration compared to control. It is the "framework" of the samples obtained with the maximum content of vegetable coagulant that determines the greater rigidity of the structure, and therefore provides the best structural and mechanical characteristics and, accordingly, the moisture-retaining capacity. According to the indicator of water activity (Aw), which shows the influence of enzymatic, microbiological and other processes on the intensity of reactions, the predicted rational storage conditions for milk-plant concentrates are a temperature of 4±2 °C and a duration of 72 hours. It was determined that the evaporation of the main part of moisture from the protein-vegetable concentrate was slower by 3±0.5 min compared to the milk-protein concentrate, due to the presence of *Arachis hypogaea* proteins and carbohydrates that bind free water.

Conclusions. The feasibility of using the fruits of *Arachis hypogaea* in mixtures for thermal acid precipitation of proteins to obtain milk-plant concentrates with appropriate functional properties and increased biological value due to a more balanced amino acid composition has been proven.

Introduction

Dairy-vegetable products are widely developed and introduced into the human diet (Onopriichuk et al., 2023). The composition of essential nutrients in such products is optimized, which is ensured by the selection and combination of proteins of animal and vegetable origins (Liem et al., 2019; Savarino et al., 2021). The active use of Non-Dairy Milk is associated both with the individual intolerance of lactose and/or milk casein in a large number of consumers, as well as with the popularization of vegetarianism and the physiological benefits of vegetable protein consumption, especially in herodietic nutrition (Makinen et al., 2016; Sethi et al., 2016). There are known production of plant-based milk alternatives manufactured from nuts, legumes and cereal crops, which have a pleasant taste and smell and are also comparable by the sensory properties with traditional dairy raw materials (Cichońska et al., 2021; Rybak, 2016). As a result of precipitation of plant milk proteins and/or its mixtures with cow milk, concentrates are obtained, among which soy ones are especially common (Zheng et al., 2020). The above raw materials are used as an alternative to animal milk. And this, to a certain extent, serves to solve the problem of a general protein deficiency in the diet of the population.

The fruits of *Arachis hypogaea*, commonly known as peanuts, which have a high nutritional value due to the presence of a significant amount of easily digestible proteins and fats, could serve a suitable raw material for the production of vegetable milk. The fat (about 50%) of peanuts contains about 20% saturated and 80% unsaturated fatty acids, of which oleic and linoleic acids occupy the largest share (Ciftci et al., 2022). The protein composition of *Arachis hypogaea* fruit kernels is represented by such proteins as albumins, globulins, and glutelins. The high biological value of peanut proteins is due to their content of 8 essential amino acids and 10 replaceable amino acids, which brings it close to animal proteins by composition. It is known that the *Arachis hypogaea* fruits is rich by such amino acids as arginine, glycine, leucine, alanine and methionine, but others are present in small amounts (Cichońska et al., 2021; Rybak, 2016). The vitamin composition of Arachis hypogaea fruits is characterized by a high content of vitamins, mg/100g: E, 6.93; B1, 0.438; B2, 0.098; B3, 13.5; B5, 1.4; B6, 0.256, and B9, 145 (Settaluri et al., 2012). One of the functional components of peanuts is resveratrol, which has antioxidant, anticarcinogenic, and anti-inflammatory properties (Salesa et al., 2014). The polyphenolic composition of *Arachis hypogaea* fruits is mainly represented by n-coumaric and ferulic acids, esterified derivatives of n-coumaric and hydroxybenzoic acids (Dubinina et al., 2017). The above-mentioned polyphenolic compounds have antioxidant properties (Pavlyuk et al., 2019). Therefore, *Arachis hypogaea* fruits have a high content of biologically active substances, which makes it possible to recommend it for use in the technology of multicomponent milk plant concentrates. Products with a multicomponent composition are good for health and have a lower calorie content compared to traditional ones (Bocker et al., 2022). In addition to direct consumption, plant milk is also used as a basis for the preparation of traditional dairy products such as cream, yogurt, cheeses and ice cream (Gomes et al., 2021; Montemurro et al., 2021).

The aim of the present research was to study the quality indicators of multicomponent concentrates obtained by thermal acid precipitation of proteins from the dairy-vegetable mixture of the skimmed milk with the fruits of *Arachis hypogaea*.

Materials and methods

Preparation of dairy-vegetable concentrates

Skimmed milk with a mass fraction of solids 11.5%, protein 3.6%, active acidity 6.5, which was produced by separating and removing the fat from whole milk, was chosen as the dairy base.

Dairy-vegetable suspension was added to skimmed milk in amounts of 10, 20, 30, and 40%, which corresponds to the ratio of components in milk-vegetable mixtures as 9:1, 4:1, 7:3, 3:2. They had an active acidity of 6.7±0.1 pH units, with the size of the dispersed phase ranging from 10 to 60 µm. To obtain the milk-plant suspension of *Arachis hypogaea* fruits, they were pre-soaked and left to swell for 8-10 hours, washed 2-3 times, poured with low-fat milk whey in a ratio of 5:1 to the fruits, after which the resulting mixture was ground to a homogeneous state for 5-7 minutes in a disperser with a speed of 1000 s^{-1}. The resulting dairy-vegetable mixture was filtered and added to the prepared skimmed milk.

The dairy-vegetable concentrate was obtained from the dairy-vegetable mixture by the method of thermal acid precipitation of proteins. The acidity and the amount of coagulant were selected in such a way as to reach the pH of the mixture in the range of 5.3–5.8, which corresponds to the isoelectric point of casein and the main fractions of plant proteins. The coagulation process was carried out at a temperature of 92±2 °C by addition of the dairy-vegetable mixture to whey, the acidity of which was 150±10 °T in a ratio of 1:10 ÷ 5:10 and holding for 4±1 min. Under these conditions, the pH of the mixture reaches the isoelectric point of the proteins, the salt bonds of its particles are destroyed, and a concentrate is formed, which is then subjected to self-pressing for (30±2) min. A milk-protein concentrate without the addition of a dairy-vegetable mixture was used as control.

Methods

Order of the research. During the experiments, standard and well-known methods to determine quality indicators were used.

The yield (mass) was determined by the weighing method (in grams): the sample was weighed after self-pressing the concentrate obtained from 1 dm^3 of the dairy-vegetable mixture.

The water-retaining capacity (WRC) of multicomponent dairy-vegetable and milk-protein concentrates was determined by method based on the determination of the water amount that is released from the product by light pressing, which is absorbed by filter paper.

The mass fraction of moisture was determined by the thermogravimetric method on the ADGS 50 series electronic laboratory scale-hygrometer.

Determination of moisture. Determination of moisture was carried out by the thermogravimetric method on a laboratory electronic hygrometer ADGS 50 manufactured by the company "AXIS" (Poland). The method consists in determining the mass of the studied sample before and after drying it by heating to a temperature not higher than 160 °C. The hygrometer scales are equipped with general-purpose laboratory weights of accuracy class 3 with a built-in drying device and have the following characteristics: the largest/smallest weighing limit 50/0.02 g; discreteness of reading mass values is 0.5 mg; limit of permissible error of mass determination is 0.5 mg; the limit of the permissible error of moisture determination is 0.3%.

Evaporation of moisture from the sample during heating leads to a decrease in its mass, which makes it possible to calculate the moisture content in the sample, which was before the sample drying process, based on the mass measurement data. Determination of moisture in the sample can be carried out with the same accuracy at significantly different values of the drying temperature of the sample (the difference will be only at the time of conducting the study). The principle of moisture determination consists in automatic mass measurement before, during and after drying of samples. Moisture is calculated automatically by the hygrometer according to the formula (Grek et al., 2017). Automatic termination of the drying procedure occurs if the difference between several consecutive measurements of the mass of the sample does not exceed 20 mg.

Photomicrographs of multicomponent dairy-vegetable and milk-protein concentrates were obtained using a fluorescence and phase-contrast microscope XSP-139A-TP (Manufactured by Shanghai Sanshen Medical Instrument Co., LTD, China) with a Canon-66 digital camera (at a magnification of x 600). Structural and mechanical characteristics were studied after long-term pressing of concentrates and maximum extraction of whey.

Determination of water activity of model samples of concentrates was carried out on a Rotronic hygrometer of the Hygro Palm AW modification (Switzerland). Measurement range: water activity 0–1 aw (0–100 %), temperature from minus 10 to plus 60 °C. Limits of absolute error±1% (± 0.008 aw),±0.1 °C. The range of application of the electronic unit is 0–100 %, minus 20 to plus 60 °C. The hygrometer consists of a manual unit with a display, control keys and a water activity measuring probe. The analysed sample is taken into a container and placed in the measuring chamber. A water activity probe is installed from above. The electrodes provide a signal based on the relative humidity in the closed chamber, which is converted by software. The measurement cycle lasts 3–5 minutes at room temperature, after which the water activity and temperature values are shown on the screen.

Statistical analysis

Data were expressed as means±standard deviations for triplicate determination. Differences were considered to be significant at validity of α=0.95.

Results and discussion

Determination of the optimal ratio of skimmed milk and dairy-vegetable suspension in mixtures for precipitation

The maximum possible level of replacement of skimmed milk with dairy-vegetable suspension in mixtures for precipitation was determined, taking into account the yield, physico-chemical and sensory indicators of multicomponent dairy-vegetable concentrates. Model samples were prepared from skimmed milk and dairy-vegetable suspension in the ratio of components 9:1, 4:1, 7:3, 3:2, the active acidity of them was pH 6.7±0.1. The choice of the optimal ratio was based on the preservation of normative physico-chemical indicators characteristic of milk-protein concentrates, which can be the basis for the production of various types of cheese products. In addition, the intensity of precipitation of proteins of dairy-vegetable mixtures and the duration of high-temperature processing, which depends on the yield of concentrates, were taken into account (Kamal et al., 2021).

The change in yield and mass fraction of moisture of milk-plant concentrates depending on the ratio of components in mixtures with *Arachis hypogaea* fruits is shown in Figure 1.

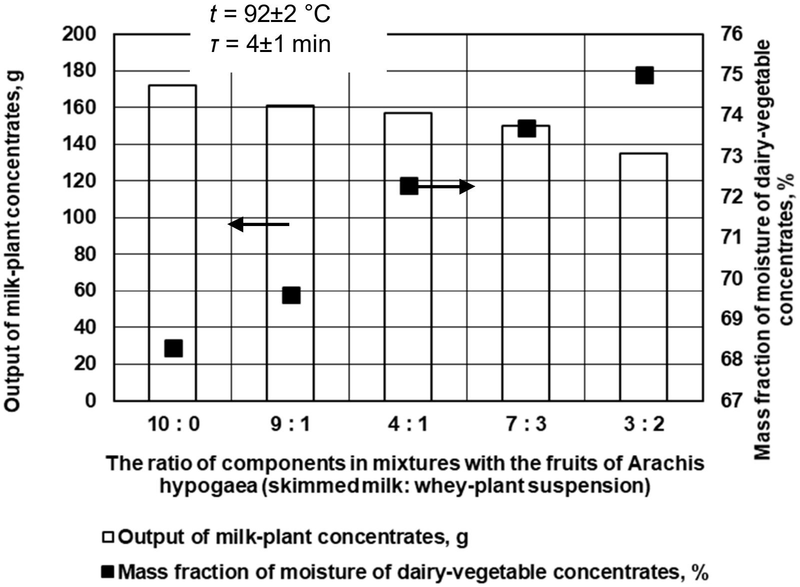


Figure 1. Yield and mass fraction of moisture of milk-plant concentrates depending on the ratio of components in mixtures with *Arachis hypogaea* fruits

The obtained concentrates are polydisperse colloidal systems, in which the dispersion medium is whey, and the dispersed phase is proteins and fats of plant and animal origin. The stability of protein globules is due to the conformation of the particles, the determined charge and the presence of a hydrated shell (Ifeanyi et al., 2021). For the separation of milk and vegetable proteins, it is necessary to break the balance of at least two factors of stability, which occurs during thermal denaturation (Dumpler et al., 2020). This process is accompanied by a change in the configuration, hydration and aggregate state of the particles, which become less stable (Huppertz et al., 2016). In addition, the degree of thermal denaturation of protein globules in dairy-vegetable mixtures depends on the temperature and duration of heating (Čurlej et al., 2022). The use of the proposed heat and time regimes makes it possible to carry out simultaneous coagulation of both milk proteins – caseins, albumins, globulins, and vegetable proteins – glutelins. The main part of the fat contained in the fruits of *Arachis hypogaea* is concentrated together with the proteins during precipitation, the rest is lost in the whey. Because of heating dairy-vegetable mixtures to a temperature of 92±2 °C in the presence of a coagulant (acidic whey), proteins co-precipitate in a single protein complex, which also includes a fat component.

The results of the research (Figure 1) showed a tendency to decrease the yield and increase the mass fraction of moisture of the obtained dairy-plant concentrates with an increase in the amount of introduction of the dairy-vegetable suspension from the fruits of *Arachis hypogaea*. Under the same conditions of the thermal acid precipitation process with a change in the ratio in mixtures from 9:1, 4:1, 7:3 to 3:2, a decrease in the yield of dairy-vegetable concentrates by 4.16–10.11% compared to milk-protein concentrate is observed obtained exclusively from dairy raw materials. This effect is associated with a decrease in the total mass fraction of protein in mixtures in which a part of skimmed cow milk is replaced by whey and vegetable components of *Arachis hypogaea* fruits.

It was shown that the peculiarities of the composition of dairy-vegetable mixtures affect the process of dehydration of concentrates. The indicators of the mass fraction of moisture in the concentrates obtained under the same pressing conditions increased from 68.25 to 73.36%, depending on the ratio of components in the mixtures (Fig. 1). In particular, dairy-vegetable concentrates, which were obtained from skimmed milk and dairy-vegetable suspension in a ratio of 9:1, had a creamier consistency compared to the control sample. With a change in the ratio in the mixture to 3:2, concentrates with a delicate pasty consistency were obtained, while the process of whey separation (self-movement) was prolonged.

The change in the moisture-retaining capacity of multicomponent dairy-vegetable concentrates depending on the ratio in mixtures of skimmed milk and dairy-vegetable suspension with *Arachis hypogaea* fruits was studied, which shows the effect on the structure and quality indicators of the finished product (Figure 2).

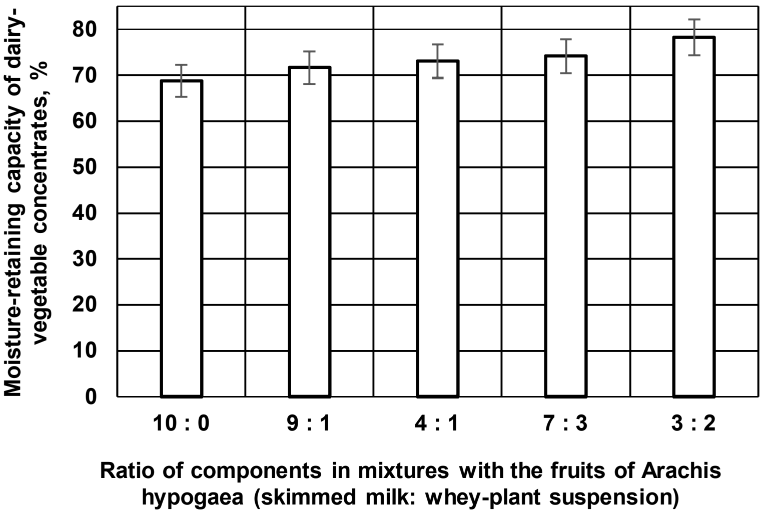


Figure 2. Changes in the moisture-retaining capacity of milk-vegetable concentrates depending on the ratio in mixtures of skimmed milk and dairy-vegetable suspension with *Arachis hypogaea* fruits

The results of research (Figures 2, 3) indicate an increase in the strength of multicomponent dairy-vegetable concentrates with an increase in the amount of dairy-vegetable suspension with the fruits of *Arachis hypogaea*. The moisture-retaining capacity of the model samples of the concentrates increased with the compaction of their structure. Thus, when the ratio of components in the mixtures was 3:2, the indicator of moisture retention was the highest and was 78.25±0.1%, which indicates an active decrease in the surface charge of micelles, which is a factor of colloidal destabilization of the protein phase of the mixtures (Anema et al., 2013).

According to the results of the quality indicators and yield of multicomponent milk-vegetable concentrates, the optimal ratio in mixtures of skimmed milk and dairy-vegetable suspension with *Arachis hypogaea* fruits was determined at the level of 7:3. Such concentrates retain a milky taste and aroma with a light peanut flavour, a uniform paste-like consistency. At a ratio of skimmed milk to dairy-vegetable suspension 3:2, a decrease in the yield of the concentrate by 22.62% was observed, with a too pronounced taste and aroma of peanuts.

Figure 3. Visualization of milk-vegetable concentrate obtained from a mixture with a ratio of skimmed milk and dairy-vegetable suspension with *Arachis hypogaea* fruits – 7:3

Polycomponent microstructure of dairy-vegetable concentrates

For the production of multicomponent dairy-vegetable concentrates of appropriate quality, it is necessary to take into account the changes that occur with the protein component in the mixtures during thermal acid deposition (Oliveira et al., 2022). One of the main parameters of such concentrates is the consistency of the product (Janahar et al., 2022). The structure of the concentrates was recorded microscopically using a fluorescent and phase-contrast XSP-139A-TP microscope with a Canon-66 digital camera (at a magnification of x 600).

In order to determine the features of the structure of the dairy-vegetable concentrate obtained from a mixture with the optimal ratio of skimmed milk and whey-plant suspension with the fruits of *Arachis hypogaea* – 7:3, comparative studies of the microstructure of the control and experimental samples were conducted (Tables 1, 2).

Table 1

Parametric characteristics of the concentrates microstructure, µm

Type of concentrate	Areas with compacted protein structure	Fat splash	Microvoids
Milk-protein (control)	60–380	–	35–120
Dairy-vegetable	50–520	7.5–11.5	35–90

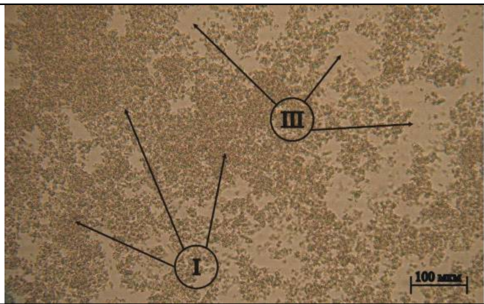
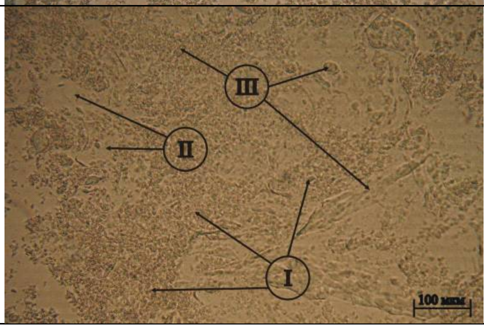
The microstructure of the dairy-vegetable concentrate consists of areas with a compacted protein structure with interspersed fat and microvoids of irregular shape and has differences compared to the milk-protein (control) (Tables 1, 2).

The microstructures of dairy-vegetable and milk-protein concentrates, having much in common, differ in the number of fat inclusions distributed in the protein phase in the form of large and small particles. However, there is a uniform distribution of fat with high dispersion – 5–7 microns.

It is obvious (Table 2) that the microstructure of the dairy-vegetable concentrate had different features from the control.

Table 2

Characteristics of the concentrates' microstructure

Type of concentrate	Photomicrographs of concentrates	Characteristics of the microstructure
Milk-protein (control)		Homogeneous, consisting of coarsely dispersed and finely dispersed protein aggregates (I), between which microvoids of irregular shape are located (III)
Dairy-vegetable		Solid, consisting of finely dispersed protein aggregates (I), between which there are single inclusions of vegetable fat with an average size of 10 μm (II), single inclusions of fibers of vegetable raw materials with a length of up to 60 μm (III)

The microstructure of the milk-vegetable concentrate had different features from control (Table 2). They have a pronounced homogeneous consistency. Their microstructure is uniform and includes evenly distributed micropores of minimal size with fat inclusions. In the micrographs of concentrates obtained from a mixture of skim milk and dairy-vegetable suspension with *Arachis hypogaea* fruits – 7:3, the protein structure consists of particles more densely connected to each other than in the control sample. The structure of the concentrate has a more developed spatial configuration – a "framework" characteristic of tightly dispersed systems, which prevents the free mutual movement of its links (Oliveira et al., 2022). Greater stiffness of the structure provides the best structural and mechanical characteristics and moisture retention capacity for the experimental sample. In samples of dairy-vegetable concentrate, such a component as fat is distributed evenly in the form of small inclusions. The dispersion of fat components in model samples is determined by the structure of the protein concentrate.

State of moisture and water activity in multicomponent dairy-vegetable concentrates

In order to determine the qualitative and quantitative state of moisture in the multicomponent milk-vegetable concentrate in comparison with control, the dynamics of water evaporation from model samples was determined on electronic scales-hygrometers of the company "AXIS", presented in Figure 3.

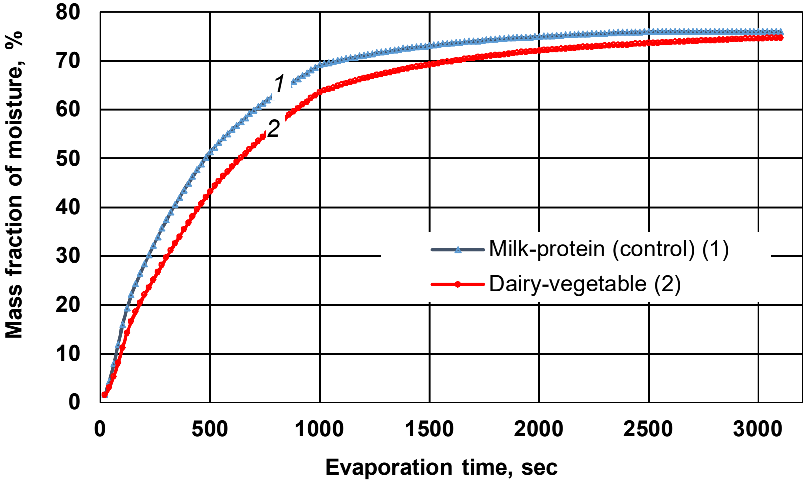


Figure 3. Dynamics of moisture evaporation from concentrates: milk-protein (control) and milk-vegetable with a ratio of components in the mixture of 7:3

According to the measurement results, the extraction of the main part of moisture (free) from the sample of milk-protein concentrate (control) occurred more intensively by 15.8±0.1% compared to the dairy-vegetable concentrate. During thermoacidic coagulation, irreversible reactions of deposition of protein substances occur with the loss of native properties, which is accompanied by the unfolding of polypeptide chains of protein molecules (Verruck et al., 2019). Because of such chain transformations and destruction of tertiary and secondary structures, hydrophobic groups appear on the surface of protein molecules. At the same time, protein substances lose their solubility, aggregate and precipitate (Li et al., 2021; Osman et al., 2020). Probably, the interaction of skimmed milk and whey proteins with the components of *Arachis hypogaea* fruits leads to the formation of additional complexes that differ in the presence of strong bonds between them. From a practical point of view, the use of a whey-plant suspension with the fruits of *Arachis hypogaea* in the composition of mixtures for thermoacidic coagulation of proteins will provide a higher amount of bound moisture.

The study of water activity of multicomponent dairy-vegetable concentrates was carried out according to the methodology that has already been used for milk-protein concentrates and is sufficiently informative (Sukmanov and Sklyarenko, 2012). Technological and consumer properties, the shelf life of such products are largely determined by the properties of the water contained in them. The level of water activity records the impact of the intensity of reactions, such as lipid oxidation, the activity of enzymatic, microbiological and other processes. With the help of the water activity indicator, a relationship is found between the presence of water available for microorganisms in the product and the probability of vital activity of certain types of microflora (Allen, 2018). Thus, by controlling the "water activity" (Aw) indicator, it is possible to predict optimal conditions and storage capacity. According to the level of "water activity", products with high (Aw = 1.0–0.9), intermediate (Aw = 0.9–0.6) and low moisture content (Aw = 0.6–0.0). The value of "water activity" in multicomponent milk plant concentrates is presented in Table 3.

Table 3

Water activity (A_W) in multicomponent dairy-vegetable concentrates (n = 3, p≥0.05)

Type of concentrate	**Ratio of components in mixtures**		**Water activity Aw**
	Skimmed milk	**Whey-plant suspension with *Arachis hypogaea* fruits**	
Milk-protein (control)	10	–	0.955
Dairy-vegetable	9	1	0.958
	4	1	0.963
	7	3	0.972
	3	2	0.974

The studied dairy-vegetable concentrates belong to high-moisture foods (A_w = 1.0–0.9). Most of the moisture is in a free, unbound state, which enables the development of biochemical and oxidative processes (Grek et al., 2019). Such concentrates have a rather limited shelf life under appropriate temperature conditions (Trmcic et al., 2016). The difference in values of water activity between control and test samples is not significant, which gives reason not to specify the conditions of storage of these concentrates, but to apply the parameters accepted in production conditions: temperature 4±2 °C and duration 72 hours.

Conclusions

1. The feasibility of using the fruits of *Arachis hypogaea* in mixtures for thermal acidic precipitation of proteins to obtain milk-plant concentrates with appropriate functional properties and increased biological value due to a more balanced amino acid composition has been proven. The results of determining the yield of concentrates, their physico-chemical and organoleptic indicators confirmed the possibility of partial replacement of skimmed milk with whey-plant suspension with *Arachis hypogaea* fruits at the ratio 7:3 in mixtures for thermal acidic precipitation of proteins.
2. The microstructure of samples of concentrates obtained from a mixture of skimmed milk and whey-plant suspension with *Arachis hypogaea* fruits with the ration 7:3 was studied. It was found that dairy-vegetable concentrates had a more developed spatial configuration compared to control. It is the "framework" of the samples obtained with the maximum content of vegetable coagulant that determines the greater rigidity of the structure, and therefore provides the best structural and mechanical characteristics and, accordingly, the moisture-retaining capacity.
3. According to the indicator of water activity (Aw from 0.974 to 0.955), rational conditions and the ability to store milk-plant concentrates are predicted: temperature 4±2 °C and duration 72 hours. It was determined that the better release of the main part of moisture from the protein-vegetable concentrate was slower by 3±0.5 min compared to the milk-protein concentrate, due to the content of *Arachis hypogaea* proteins and carbohydrates that bind free water.

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