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CERTAIN FEATURES OF USING MODIFIED COLLAGEN-CONTAINING RAW MATERIALS WITH PROLONGED SHELF LIFE IN FOOD TECHNOLOGY

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Abstract

In the current circumstances, trends in nutrition of a person striving to lead a healthy life-style require intake of meat products with the reduced energy value, minimal amounts of fat, increased protein mass fraction, presence of substances improving homeostasis of the body. The synergism of the modern nutrition science and meat industry enables creating food products that satisfy consumers' demand. Today, in the Russian Federation, a theoretical and practical base of the technology development has been collected to the full extent in the field of rational processing of secondary raw materials in the food industry, optimal use of animal secondary raw materials, study of the protein ingredients of animal and plant origin and their deep scientifically substantiated processing, improvement of technological processes and equipment, and correspondently, product range extension. The paper broadens the information about the modified collagen-containing raw materials (cattle rumen), examines physico-chemical characteristics of the collagen-containing raw material and its changes in the process of freeze-drying with a special attention paid to the study of changes in the histological structure. The presence of the relatively uniform fibrillar structure was determined, which facilitated discovering the functional potential of proteinoids that form the fibrillar matrix in the composition of products from different groups. Analysis of IR-spectra revealed several significant absorption bands linked with the state of peptide bonds. The character of bands is linked with the complex of valence and deformation vibrations of the N- and C- types. It is believed that IR-spectra reflect conformations in the protein secondary structure, which suggests preserving properties of the tropocollagen particle or collagen molecule. Freeze-dried modified collagen-containing cattle rumen was tested by the example of jellies. The obtained databank broadens information about physico-chemical properties of modified collagen-containing raw materials (cattle rumen).

1. Introduction

Nowadays, the questions of population nutrition are a huge physiological and hygienic problem. Materials from studies show that over the last years actual nutrition of certain population groups in the country has been characterized by a decrease in consumption of meat, dairy and fish products, as well as fresh vegetables and fruit. A reduced energy intake with food (91%), especially from animal proteins, should be considered an unfavorable fact. The content of vitamins in diets of certain population groups is 55–60% of the recommended level [1,2].

Decree of the RF Government No.1364-p of June 29, 2016 approved the "Strategy for Improving the Quality of Food Products in the Russian Federation until 2030"[1], according to which it is necessary to develop and introduce innovative resource saving technologies within the framework of processing agricultural resources that would enable extending a range and volume of production of specialized, functional and enriched foods.

Within the same context, the national projects "Public Health" and "Demography" were adopted by Decree of the RF President No. 204 of May 7, 2018 "On national goals and strategic objectives of the development of the Russian Federation for the period up to 2024"[2], which determine the priority of supporting the life quality of the population and development of the healthy society with the aim of achieving life expectancy of 80 years in the short-term period (up to 2030).

At present, a deficiency of dietary fibers, peptides, amino acids and other physiologically active ingredients is observed in the nutrition structure. A solution to this problem to a large extent can be based on the use of the best available techniques on the basis of resource and health saving [1,2,3].

Achievements of biotechnology and its increasing use in the food industry enable not only extending product

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[1] Decree of the RF Government No.1364-p of June 29, 2016 "Strategy for Improving the Quality of Food Products in the Russian Federation until 2030"/ http://static.government.ru/media/files/9JUDtBOpqmoAatAhvT2wJ8UPT5Wq8qIo.pdf

[2] Decree of the RF President No. 204 of May 7, 2018 "On national goals and strategic objectives of the development of the Russian Federation for the period up to 2024" https://www.economy.gov.ru/material/file/ffccd6ed40dbd803eedd11bc-8c9f7571/Plan_po_dostizheniyu_nacionalnyh_celey_razvitiya_do_2024g.pdf

assortment, but also ensuring their correspondence with the concepts of the theory of adequate nutrition. In the existing economic situation, enterprises manufacturing food products from animal raw materials pay more and more attention to the use of non-traditional sources of raw materials — secondary resources, in particular, those with the high content of connective tissue. It is necessary to note that national and foreign professionals of the industry carry out multifaceted work to create protein products as fat replacers and components that are able to show properties of dietary fibers for their use in meat products, which correlate with the scope of the present work. In particular, according to their functional and physiological properties, collagen and products of its destruction can be assigned to fibrillar, anisotropic, three dimensional food systems, which are a template basis for sorption of certain components.

It was established in the complex investigations that the impact of dietary fibers within the framework of functional food products on the processes of the symbiotic and own human digestion in the gastrointestinal tract leads to an improvement in clinical metabolic (normalization of the functional activity of intestinal microbiota) and anthropometric parameters (reduction of the body weight and waist circumference), which predetermines a possibility to use dietary fibers within programs on treatment and prevention of obesity [4,5].

For example, the studies were carried out to determine sorption properties of collagen fermentolysate relative to heavy metals by the example of Cd^{2+} and Pb^{2+} ions. The results allow stating that in terms of the ability to bind Pb^{2+} ions, the product of biomodification of the connective tissue protein is comparable with cellulose, for which sorption of ions of this element was recorded in a range of 0.10–0.23 mg/g [6]. Therefore, the hydrolyzed forms of collagen are able to bind heavy metal ions in the digestive tract with formation of insoluble complexes that are not absorbed and are excreted from the body. This mechanism can be used to prevent poisoning with heavy metal salts.

The process of the combined sorption of several protein components and bioactive substances is also of interest. Systematic study of sequential and combined sorption of several binary protein mixtures and some bioactive substances (for example, ion-exchange components of plant origin — ascorbic acid, iodine) show that the process of binding is complicated by the phenomena of synergism. It has been established that the synergetic phenomena in sorption processes are facilitated by strong binding of protein with certain components of different nature, which is possible to determine by the number of fixed ionogenic groups of a sorbent on a protein molecule. A decrease in the local concentration of ionogenic groups of bioactive components of plant origin favors transition to the synergetic mechanism of competitive sorption. As a result of such sorption of bioactive substances on the matrix collagen base, it is possible to increase preservation of compo-

nents that are easily destructible at heat treatment such as ascorbic acid and iodine in the organic form up to 70% [7].

It is worth noting that the mechanism of such sorption has not been determined. However, it is known that all proteins are characterized by the pronounced ability to non-specific binding to the SH-groups, guanidine group of arginine and other constituents of amino acids. It is possible that biomodification of connective tissue facilitates disruption of peptide chains of collagen; as a result, the above mentioned functional groups become more available for interaction with metals and biologically active substances [8].

Therefore, modified (chemically, physically or by biomodification) connective tissue is a sorbent with the high activity for heavy metals and biologically active substances and can be used in the future as a functional additive in production of foods, in particular meat products [9,10,11].

An acute need for increasing the human adaptive potential stemmed from the increasingly aggressive impact of both ecological and socio-economic factors causes a necessity among professionals in the industry to create a new generation of food products which should not only provide the body with substances that are essential for the growth, development and vital activity but also stimulate its protective functions.

The aim of the research is the development of the technological solutions in production of jellies based on determination of certain peculiarities in the raw materials occurring in the process of alkali-salt modification and freeze-drying.

2. Objects and methods

Objects of the research were samples of cattle rumen (15×15 mm) before and after modification. Food-grade gelatin from beef skin Bloom 220 by Gelnex (USA) was used for comparative analysis of IR-spectra. At the testing stage, beef jellies with/without modified cattle rumen were produced.

Raw materials were subjected to physico-chemical modification, which included preliminary mincing through the cutting plate (2 mm) of a grinder and treatment with a solution of edible salt (6% concentration) and sodium hydroxide with different concentrations: 3% (pH of the solution = 12.05) — sample MR-1; 5% (pH = 12.30) — sample MR –2; 7% (pH = 12.78) — sample MR –3, where MR is modified rumen.

At the stage of the alkali-salt treatment, the hydromodule was 1:2.

Neutralization was carried out using the acetic acid solution with the concentration of 7% to specified pH values (Table 2). After obtaining collagen hydrolysates, the samples were dried using the laboratory test stand SVP-0.36 (Figure 1), which scheme is shown in Figure 2. The principle peculiarity of the construction is the presence of two systems for evacuation and cold supply. The first of them enables realizing the traditional vacuum freeze-drying with the phase transition "ice-steam", the second allows dehydration in the mode of vacuum evaporation.

Figure 1. General appearance of the test stand SVP-0.36 [12]

Working parameters of classical freeze-drying:
— Beginning of evacuation: T desubl. = minus 26 °C; T_{pr1} = –10.5 °C; T_{pr2} = 11.7 °C; T_{heat} = 22.4 °C;
— Beginning of drying: T desubl. = minus 28 °C; P_{cham} = 83 Pa; T_{pr1} = minus 25 °C; T_{pr2} = minus 24 °C,

where T desubl. is a temperature of the desublimator;

T_{pr1} is a practical temperature 1;

T_{pr2} is a practical temperature 2;

T_{heat} is a temperature of heating.

When determining indicators of the nutrition value, the following methods were used: moisture mass fraction by GOST 9793–2016[3]; protein mass fraction using the semi-automated unit Kjeltec System 1002 «Tecator» (FOSS, Denmark); fat mass fraction by GOST 23042–2015[4]; ash mass fraction by GOST 31727–2012 (ISO 936:1998)[5].
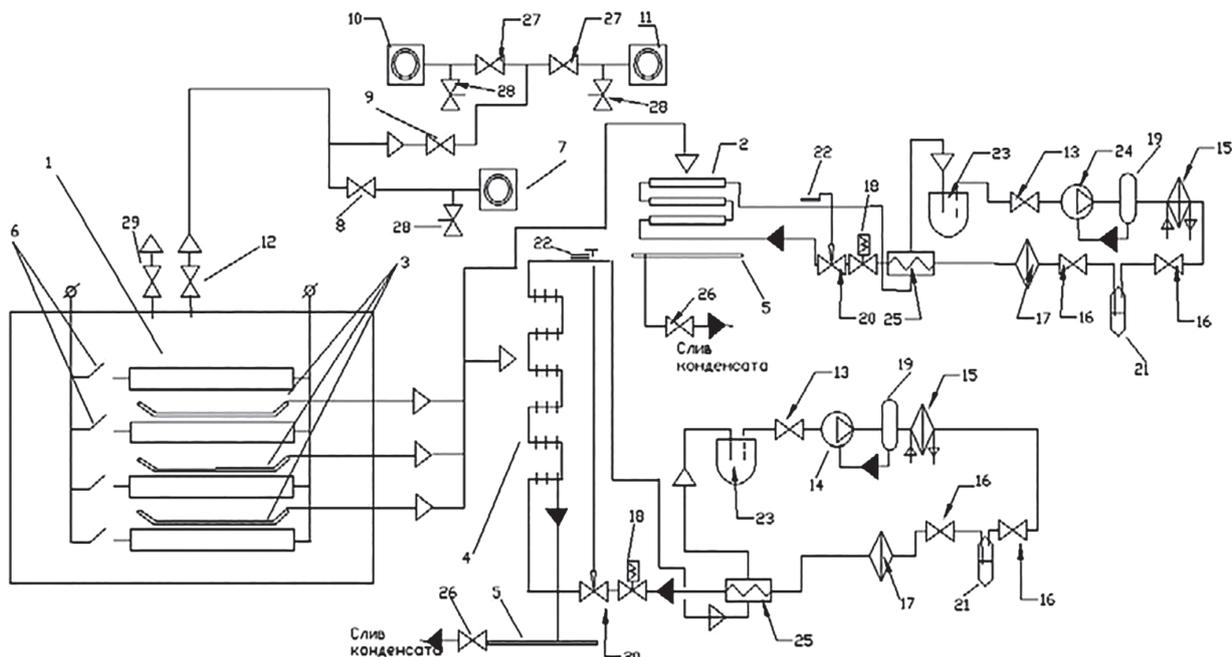

Figure 2. Principle scheme of the test stand of vacuum freeze-drying:
1 — electric heaters, 2 — desublimator, 3 — trays with a product, 4 — enclosed condenser, 5 — collection trays for condensate drain, 6 — tumbler switchers on/off of the electric heaters, 7 — vacuum aggregate NVM-5, 8 — valve SK26013–020, 9 — valve SK26013–010, 10 — vacuum aggregate 2NVR-5DM, 11 — vacuum aggregate 2NVR-01DM, 12 — valve SK26013–025, 13 — valve, 14 — compressor SC10G, 15 — air condenser, 16 — valve, 17 — filter-drier, 18 — solenoid valve, 19 — oil separator, 20 — electronic TEV, 21 — receiver, 22 — thermal bulb, 23 — liquid separator, 24 — compressor SC21CL, 25 — heat exchanger, 26 — valve, 27 — valve, 28 — leak valve, 29 — vacuum breaking valve.

The drying graph is presented as Table 1.

Table 1. Freeze-drying graph

Time, h	Weight, kg	T desubl., minus °C	Pressure in chamber, Pa	T_{pr1}, °C	T_{pr2}, °C	T_{heat}, °C	Power, W
10:00	17.98			**Beginning of evacuation**			
10:30	17.83	28	83	minus 25	minus 24	—	200
11:30	17.63	34	65	minus 25,5	minus 25	88	207
12:00	17.55	33	65	minus 25	minus 25	90	210
13:30	17.35	33	66	minus 14	minus 12	99	194
15:00	17.17	35	55	35	30	95	195
15:45	17.14	37	55	45	40	89	140
16:00	17.14	37	55	45	40	89	50

When studying a degree of *in vitro* protein digestibility, the method by Pokrovsky-Ertanov (the modified unit of MGUPB, Russia) was used.

A pH value was determined using a pH meter Testo-205 with a pH measurement range of 0.5÷14 (Testo, Germany).

Rheological properties were studied using a rotary viscometer "Polimer RPE-1M" with the system of sensing elements of the rotor-cylinder type T1-V1 (NPO "Chimavtomatika", Russia). A penetration level was measured using a

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[3] GOST 9793–2016. "Meat and meat products. Methods for determination of moisture content". Moscow: Standartinform, 2018. — 9 p. (In Russian)

[4] GOST 23042–2015 "Meat and meat products. Methods of fat determination". Moscow: Standartinform, 2019. — 8 p. (In Russian)

[5] GOST 31727–2012 (ISO 936:1998) "Meat and meat products. Determination of total ash". Moscow: Standartinform, 2019. — 11 p. (In Russian)

semi-automated penetrometer PN10 with a conic indenter with a weight of 70 g and a 60-degree angle 2 α; then, the values were recalculated into the ultimate shear stress by Rebinder's equation. Structural-mechanical properties of products, in particular, shear stress and shear strain, were determined on a universal testing machine "Instron-1140" using a Kramer shear press (Instron, USA).

Microstructural examination was performed according to GOST 19496–2013[6] using a light microscope AxioImaiger A1 (Carl Zeiss, Germany), video camera AxioCam MRc 5 and computer system for image analysis AxioVision 4.7.1.0 [13].

In addition, the Fourier transform infrared spectroscopy (FTIR) was applied using a Fourier Transform Infrared Spectrophotometer ALPHA (Bruker, USA) with a module of single attenuated total reflection with the diamond crystal intended for the universal basic spectral analysis in the mid-IR region of 375 to 7500 cm^{-1}. Sample preparation consisted in the following: powder-like samples of MR (modified rumen) were applied on the diamond crystal of the interferometer and fixed with a holding-down device; after that, a spectrum was obtained in the automated mode.

The obtained results were processed using the conventional methods of the analysis of variance. Differences in indicators were considered significant at a level of significance interval ≤ 0.05.

3. Results and discussion

Cattle rumen in the native state had pH 6.99.

Table 2. Parameters of cattle rumen modification and physico-chemical indicators of samples

Indicator	Sample		
	MR-1	MR-2	MR-3
pH of solution for akali-salt hydrolysis	12.05	12.30	12.78
pH after acid treatment	4.50	4.51	4.68
pH after additional washing	5.50	5.70	5.80
Penetration degree (I), units of apparatus, after the main stages of alkali-salt treatment	23.0 ± 2.0	60.0 ± 6.0*	36.0 ± 4.0
Ultimate shear stress (Θ) after the main treatment stages, kPa	27.79	4.08	11.34
I, units after additional washing	45,0 ± 4,0	32,5 ± 3,0*	46,7 ± 3,0*
Θ, kPa, after additional washing	7.3	13.9	6.7
Moisture mass fraction after freeze-drying,%	1.5	1.8	1.5
Ultimate shear stress after freeze-drying, kPa	2.8·10^3	0.76·10^3	1.3·10^3

* — P ≤ 0,05 (error probability)

Based on the results presented in Table 2, it is possible to see differences between the samples in rheological indicators (a penetration degree and ultimate shear stress) caused by differences in the hydration properties, interactions of the substrate and moisture according to the principle of swelling. The values of other determined indicators differed insignificantly.

To ensure long-term storage of the modified collagen-containing raw materials and to obtain samples in the powder-like form extending technological possibilities of their use in food product recipes, vacuum freeze-drying was used [14,15,16].

The process was performed to the ultimate moisture of 2%. When studying the indicators of microbiological spoilage, the shelf-life of 1.5 years was established for the obtained freeze-dried products. Preliminary rehydration (1:3) for 30 min. is recommended in meat product manufacture.

When assessing an effect of freeze-drying temperature on the complex of quality indicators of dried products, it was concluded that the most optimal freeze-drying temperature was minus 20 °C. The applied parameters of freeze-drying can be realized in the commercial freeze-drying units. The processes of preliminary freezing and subsequent vacuum dehydration with the phase transition "ice-steam", which are used in freeze-drying, inevitably lead to changes in the structure of capillaries and fibers. These changes decisively influence rehydration of dried samples and preservation of the protein structure.

As a result of freeze-drying, a firm fixed capillary porous structure of samples (xerogel) is formed. The value of ultimate shear stress after drying samples sharply increased (Table 1), which also correlates with the data of the histological studies.

Firm large bundles of collagen fibers arranged tangentially were revealed in the control sample (Figure 3a). Tinctorial properties of sections were comparatively pronounced.

The results of the microstructural analysis proved the hydrolytic destruction of collagen fibers (Figure 3b); the configuration of the section changed, for example, fiber bundles were swollen, transformed into the vitreous state, which correlates with the process of thermotropic gelation upon heat treatment [17,18,19,20].

As one of the tasks was to substantiate a possibility to include vacuum freeze- drying, which forms specific microdisperse systems of food systems, into the technological process of raw material processing, the structure after drying was studied (Figure 3c). Xerogel-type structures with cells of the disperse phase and capillaries, in which liquid was retained, were revealed in different layers.

Peculiarities of the microstructure suggest the manifestation of the fibrillar structure, presence of capillaries, which can facilitate quick rehydration of samples, and, when necessary, the use of comminution to the powder-like or fiber-like state and more rational use as a component — a source of a dietary fiber analog.

At the next stage of the work, the task of studying changes in the samples at the molecular structure level was solved by the infra-red spectroscopy using Fourier Transform Infrared Spectrophotometer ALPHA-P.

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[6] GOST 19496–2013 "Meat and meat products. The method of histological study" Moscow: Standartinform, 2019. — 12 p. (In Russian)
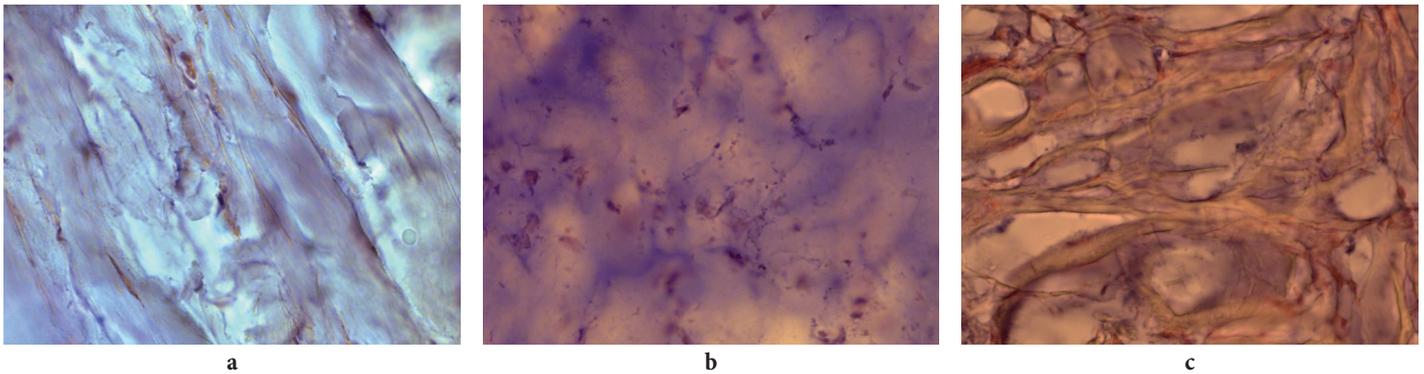
<div align="center">a   b   c</div>

Figure 3. Histological structure of samples: native cattle rumen (a, ×200),
rumen after physico-chemical modification (b, ×200), freeze-dried modified rumen (c, ×200)

As a result of the analysis of the IR-spectra (Figure 4 and Figure 5), it was established that the studied samples (control, MR-2) corresponded to the proteinoids of the connective tissue, the control to proteins of the gelatin group, according to the database incorporated into the computer of the spectrometer.

It is known that peaks characteristic of valence and deformation vibrations of different groups (–OH, CH_n, >C=O, ether groups and several others) can be found in infrared spectra.

The obtained IR-spectra in the control and modified collagen-containing raw materials (for example, MR-2) were similar; however, the peak heights varied. Therefore, taking into account the special features of the initial raw materials, we consider it expedient to compare the results with those obtained for the known protein structures. It is reasonable to compare the results of IR-spectroscopy with several domestic and foreign analogs. It is known that IR-spectra of polypeptides, proteinoids and products of their modification contain several intensive absorption bands. With that, changes linked with vibrations of amide CONH-groups, general structural elements of proteinoid molecules, were revealed.

Several absorption bands are known: amide-A (absorption band ≈ 3300 cm^{-1}), amide-B (≈3100 cm^{-1}), amide-I (1600–1700 cm^{-1}), amide-II (≈1500–1600 cm^{-1}) and so on. In principle, the corresponding peaks of absorption of IR-radiation in these ranges of wave numbers were observed in the MR samples. However, shift of several peaks to the right was observed for the samples from the studied series upon intensification of raw material processing (Figure 4 and Figure 5).

For example, in the range of 600–800 cm^{-1}, it is possible to reveal an interaction with sulfates upon "soft" acid hydrolysis. In our case, the complex processing with alkali and then acid was used, which apparently increased the polarity of protein groups and the corresponding height of the absorption band.

For comparison, we obtained the IR-spectrum for foreign food-grade gelatin (Figure 6) represented by more smoothed line, apparently due to both purification and fractional melting of proteins on the automated line of an enterprise for production of high-grade gelatin.

IR-spectra, several strong absorption bands linked with the state of peptide bonds were visualized. The character of the bonds was associated with the complex of valence and deformation vibrations of N–H and C–H types. It is believed that IR-spectra reflect well the conformation in the protein secondary structure; consequently, it is possible to expect the preservation of the properties of the tropocollagen particle or collagen molecule [21,22].
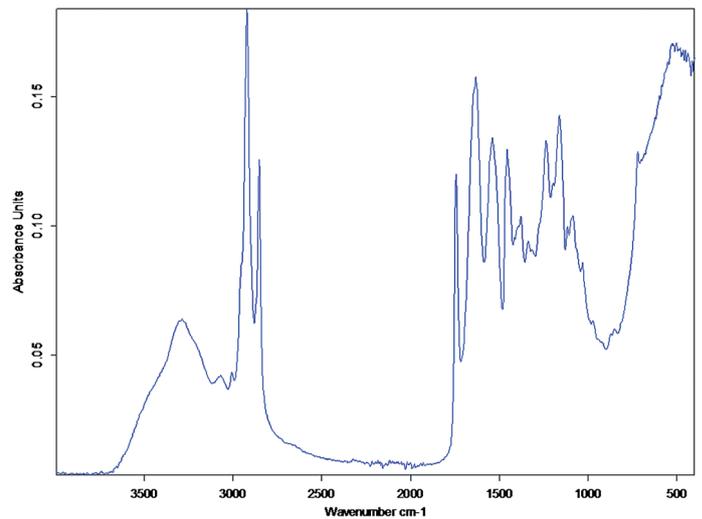

Figure 4. Infrared absorption spectrum of cattle native rumen (control)
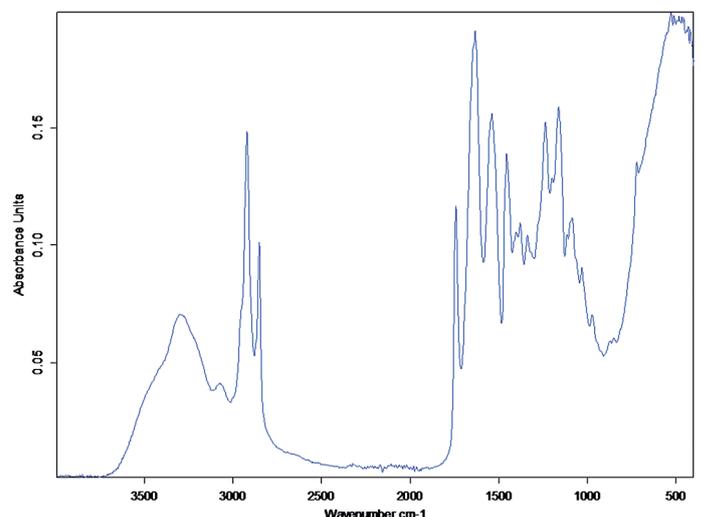

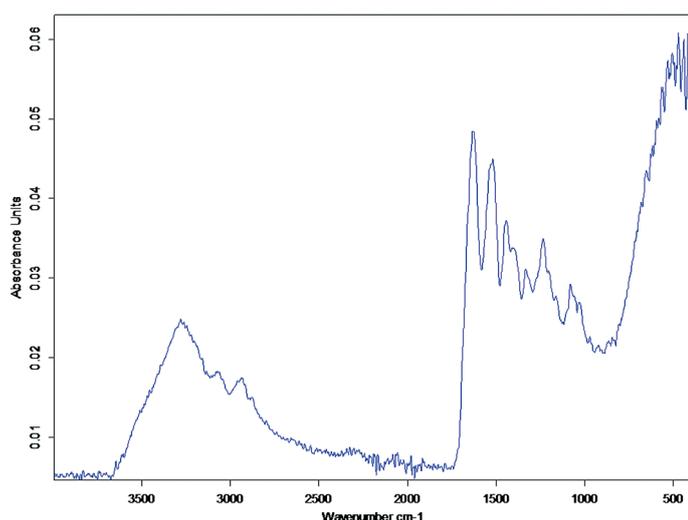**Figure 5.** Infrared absorption spectrum of sample MR-2

Figure 6. Infrared absorption spectrum of foreign food-grade gelatin

Differences found in comparison with the gelatin food additive were linked with more complex chemical composition of the studied raw materials and supramolecular-oriented architectonics of fibrils and bundles of collagen fibers. However, the comparison of the results of investigations and literature data show that, in general, the spiral conformation of proteinoids retained, which allows using the whole potential of functional and technological properties of the raw material [23].

Therefore, positive changes were established in raw materials, in particular, an increase in the lyophilic properties, defatting, bleaching, "opening" of the chemical bonds of protein. As a result of using freeze-drying with the regimes recommended by us, the longest shelf-life of the protein module is ensured. In this work, MR-2 was considered the most rational option for raw material processing (Table 2).

As fibrillar animal proteins and products of their modification are able to form jellies with significant strength, testing was carried out by producing jellies (Table 3). As a control sample, we used the beef jelly recipe; the experimental sample contained the obtained freeze-dried modified rumen instead of food-grade gelatin, which enables intensifying gelation process and enriching a product with dietary fiber analogs due to an increase in the activity of the functional groups of biopolimers (collagen) as a result of its modification.

Table 3. Recipes of processed jellies

Name	Indicators of raw material input for model systems, g	
	Control	Experiment
Beef	350/175[*]	350/175
Food-grade gelatin	12	–
Modified cattle rumen	–	34
Carrot	20	20
Onion	20	20
Black pepper	0.25	0.25
Aromatic composition	0.25	0.25
Water	According to the recipe collection	
Total, g	500	500

[*] Meat weight before and after heat treatment

The technology included cooking of the meat raw material (beef) for 3–3.5 hours. Vegetables (carrot, onion and spices) specified by the recipe were added an hour before the end of cooking. Then, meat was minced on a grinder and mixed with a broth, 2% edible salt was added and the mixture was brought to the boil with intermittent stirring. The rehydrated sample of the modified cattle rumen was added after meat mincing [24,25,26].

The obtained solutions were poured into molds and placed into a refrigeration chamber for thermotropic gelation. The recipes are variable in regard to spice addition; for example, garlic, parsley, aromatic compositions and so on can be added.

It was noticed that gelation occurred in a temperature range of 15.7–16.5 °C, which approximately corresponds to the data of A. Veis, who studied gelatins of different types [27,28]. The experimental jelly was formed faster also at a temperature of 16.5 °C, while the control was formed less intensively at 15.7 °C. This was especially obvious for the thin jelly layer (≈10 mm).

The histological structure of jelly represented a firm mass with sufficient electronic density. Pores with insignificant sizes (about 35 μm in diameter) were seen on the surface (Figure 7). In our opinion, generation of the porous structure is linked with the molecular structure of the disperse phase. As is well known, gelation is initiated by formation of a biopolymer molecule framework, which cells can contain water, solutions, fat, minor food compounds, which can be used for product enrichment with bioactive substances [29,30,31,32].
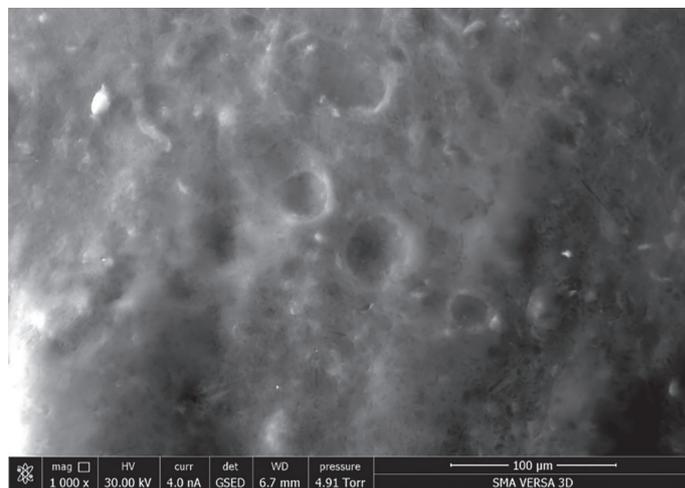

Figure 7. Electron diffraction pattern of jelly ×1000

Light microscopy images of the same samples show that the main part is represented by a homogeneous basophilically stained mass of hydrolyzed collagen, in which particles of connective tissue that more or less retained the structural organization of fibers (cellular elements were not revealed, fibers were considerably loosened), as well as individual fragments of muscle fibers were observed. At the same time, the elements of connective and muscle tissues were visualized better in the control sample compared to the experimental one.

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Chemical composition and physico-chemical indicators of the produced jellies are presented in Table 4.

Table 4. Chemical composition and physico-chemical indicators of jellies

Indicator	Samples	
	Control	Experimental
Moisture mass fraction, %	78.0 ± 3.9	74.0 ± 3.7*
Protein mass fraction, %	9.6 ± 1.0	11.3 ± 1.1*
Fat mass fraction, %	10.2 ± 1.0	10.6 ± 1.1*
Ultimate shear stress, kPa	1.2 ± 0.1	1.5 ± 0.2
Gelation temperature, ºC	15.7 ± 0.5	16.5 ± 0.5

* — P ≤ 0,05 (probability of an error between the control and experimental samples)

Indicators of digestibility are shown in Figure 8.

The energy value was 130.2 kcal/100 g in the control sample and 140.6 kcal/100 g in the experimental one. It is necessary to note that the developed jellies are a source of components (modified collagen) which exert features of dietary fibers imparting dietetic properties to products. Ultimate shear stress corresponded to the similar indicator for meat systems, structured with animal protein; the experimental sample was superior in terms of this indicator.

4. Conclusion

The complex analysis of the experimental results including the data from physical, chemical, histological, spectral methods for animal raw material investigation
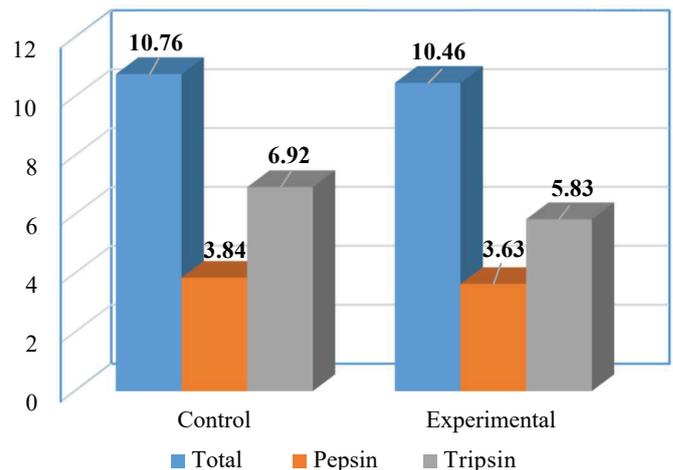

Figure 8. Indicators of *in vitro* digestibility of the samples, mg tyrosin/100 g protein

enables making a conclusion about formation of disperse food systems that corresponds to the set tasks.

The performed experiments prove conclusively a possibility and expediency of using secondary products from the meat industry to obtain biopolymer components of the multifunctional purpose. Taking into consideration formation of quite a firm, monolithic disperse system of the modified collagen-containing raw material that fixes species and other ingredients, as well as a complex of its physico-chemical indicators, it is possible to make a conclusion about a possibility to develop experimentally a broad range of foods, including meat-based products.

REFERENCES

1. Kodentsova, V.M., Vrzhesinskaya, O.A., Risnik, D.V., Nikityuk, D.B., Tutelyan, V.A. (2017). Micronutrient status of population of the Russian Federation and possibility of its correction. State of the problem. *Problems of Nutrition*, 86(4), 113–124. https://doi.org/10.24411/0042–88 (In Russian)
2. Kochetkova, A.A., Kodentsova, V.M., Vorobyeva, V.M., Vorobyeva, I.S., Vrzhesinskaya, O.A., Smirnova, E.A. et al. (2021). Fortification of food with nutrients: development of methodological and regulatory framework in the Russian Federation. *Theory and practice of meat processing*, 6(3), 269–278. https://doi.org/10.21323/2414–438X-2021–6–3–269–278
3. Ugolev, A.M. (1991). Theory of adequate nutrition and trophology. Saint-Petersburg: The science, 1991. (In Russian)
4. Kurmangulov, A. A., Dorodneva, E. F., Troshina, Irina. A., Petrova, Yu. A., Golubeva, T. I. (2018). Effects of inclusion of dietary fibers in the composition of the diet in obesity. *Obesity and Metabolism*, 15(2), 35–39. https://doi.org/10.14341/omet8785 (In Russian)
5. Borodina, S. V., Gapparova, K. M., Zainudiniv, Z. M., Grigorian, O. N. (2016). Genetic predictors of obesity development. *Obesity and Metabolism*, 13(2), 7–13. https://doi.org/10.14341/omet201627–13 (In Russian)
6. Kiikova, A.S., Antipova, L.V., Storublevtsev, S.A. (2011). Hydrolyzed collagen is an analog of dietary fiber of animal origin. *Advances in Current Natural Sciences*, 7, 118–119. (In Russian)
7. Titov, E.I., Litvinova, E.V., Kidyaev, S.N., Artemeva, I.O. (2019). Collagen matrix as a way of preservation of minor components in food products. *Vsyo o Myase,* 1, 40–43. https://doi.org/10.21323/2071–2499–2019–1–40–43 (In Russian)
8. Yugay, A.V., Boytsova, T.M. (2015). To the question of multifunctional use of a collagen received from skin of fish. *Fundamental Research*, 2(4), 704–707. (In Russian)
9. Parakhonskiy, A.P. (2005). Actual problems of rational nutrition of the population. *Modern high-tech technologies,* 6, 49–50. (In Russian)

10. Hoeling, A., Volkov, V.V. (2015). Proteins from by-products — innovative components in sustainable industrial production. *KSTU News,* 38, 83–92. (In Russian)
11. Danilov, A.M., Bazhenova, B.A. (2020). The use of pastes of the modified rumen in the composition of the sausage meat. *Vsyo o Myase,* 2, 35–39. https://doi.org/10.21323/2071–2499–2020–2–35–39 (In Russian)
12. Titov, E.I., Semenov, G.V., Kidyaev, S.N., Litvinova, E.V. (2016). Production of high-quality dry modified collagen products by means of freeze-drying. *Journal of International Academy of Refrigeration*, 3, 27–30. (In Russian)
13. Zinina, O.V., Tazeddinova, D.R. (2018). Characteristics of protein enrichers from by-products. *KSTU News*, 48, 100–111. (In Russian)
14. Titov, E.I., Apraksina, S.K., Litvinova, E.V. (2015). The effect of biomodification on the properties of collagen-containing raw materials. *Innovation and Investment*, 6, 196–199. (In Russian)
15. Gayazova, A.O., Prokhasko, L.S., Popova, M.A., Lukinykh, S.V., Asenova, B.K. (2014). The use of secondary and vegetable raw materials in functional products. *Young Scientist*, 19, 189–191. (In Russian)
16. Artemeva, I.O. (2018). The use of a collagen-containing complex in the technology of meat products. *Bulletin of the Russian State Agrarian Correspondence University*, 28(33), 20–23. (In Russian)
17. Morozova, S.A., Yezhkova, G.O., Ponomarev, V. Ya., Ananiadis, E.G., Yafasova, M.I. (16–19 April, 2019). *Obtaining protein hydrolizates from collagen-containing raw materials and their application in the meat industry*. Materials of the XV All-Russian Conference of Young Scientists, Postgraduates and students with international participation: Food Technologies and Biotechnologies, Kazan, 2019. (In Russian)
18. Charron, P. N., Braddish, T. A., Oldinski, R. A. (2019). PVA-gelatin hydrogels formed using combined theta-gel and cryo-gel fabrication techniques. *Journal of the Mechanical Behavior of Biomedical Materials*, 92, 90–96. https://doi.org/10.1016/j.jmbbm.2019.01.002

19. Semenov, G.V., Krasnova, I.S., Petkov, I.I. (2017). The choice of parameters for vacuum freeze-drying of dry heat-sensitive material with predetermined properties. *Journal of International Academy of Refrigeration*, 1, 18–24. https://doi.org/10.21047/1606–4313–2017–16–1–18–24 (In Russian)

20. Pchelkina, V.A., Khvilya, S.I. (2015). Practical aspects of application of GOST 31474–2012 "Meat and meat products. Histological method of plant protein additive identification". *Food Processing: Techniques and Technology,* 3(38), 51–55. (In Russian)

21. Zinina, O. V., Rebezov, M. B. (2013). Changes in the microstructure of a rumen in the process of enzymatic processing. *Polythematic Online Scientific Journal of Kuban State Agrarian University,* 88, 1014–1023. (In Russian)

22. Вагина В. А., Рыжова Д. Ю. Vagina, V.A., Ryzhova, D. Yu. (2021). ИК-Фурье-спектроскопии Features of measurements by IR-Fourier spectroscopy. *Acoustooptic and radar methods for information measurements and processing,* 63–65. (In Russian)

23. Balashov, A.A., Vaguine, V.A., Khorokhorin, A.I., Golyak, I.S., Morozov, A.N. (2017). Multichannel dynamic fourier-transform ir spectrometer. Journal of Applied Spectroscopy, 2017. T. 84(4), 664–667. https://doi.org/10.1007/s10812–017–0526–z

24. Storublevtsev, S.A. (2021 Evaluation of the gel-forming ability of the hydrolyzed form of collagen.. *Innovation Science*, 11–2, 33–34. (In Russian)

25. Baydalinova, L.S., Lyapustina, E.E. (2018). Obtaining of natural structure-formers of protein origin from collagen-containing secondary fish raw materials. *KSTU News*, 51, 45–60. (In Russian)

26. Voroshilin, R. A., Prosekov, A. Yu., Kurbanova, M. G. (2021). Obtaining dry protein concentrates from secondary gelatin products. *New Technologies,* 17(2), 15–24. https://doi.org/10.47370/2072–0920–2021–17–2–15–24 (In Russian)

27. Veis, A (1971). The macromolecular chemistry of gelatin. New York: Academic Press, 1964

28. Titov, E.I., Kidyaev, S.N., Litvinova, E.V., Tsurikova, N.V. (2016). Effect of alkaline proteases on modification of collagen containing raw material. *Meat Industry*, 2, 44–46. (In Russian)

29. Titov, E.I., Litvinova, E.V., Kidyaev, S.N., Pchelkina, V.A. (2017). About the microstructure of collagen-containing raw materials modified with alkaline proteinases. *Meat Industry*, 8, 41–43. (In Russian)

30. Lukin, A.A., Merenkova, S.P. (2016). A method for producing a protein stabilizer sausage. *Technology and Merchandising of the Innovative Foodstuff*, 1(36), 15–19. (In Russian)

31. Borges, J. G., Silva, A. G., Cervi-Bitencourt, C. M., Vanin, F. M., Carvalho, R. A. (2016). Lecithin, gelatin and hydrolyzed collagen orally disintegrating films: Functional properties. *International Journal of Biological Macromolecules*, 86, 907–916. https://doi.org/10.1016/j.ijbiomac.2016.01.089

32. Jansen, K. A., Licup, A. J., Sharma, A., Rens, R., MacKintosh, F. C., Koenderink, G. H. (2018). The role of network architecture in collagen mechanics. *Biophysical Journal*, 114(11), 2665–2678. https://doi.org/10.1016/j.bpj.2018.04.043

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