

Modification of Protein Products from Sesame Seeds by the Complex Action of Thermodenaturation and Extremely Low Frequency Electromagnetic Fields for Optimizing Functional Properties

Natalia Bugayets
Institute of Food and
Processing Industry
Kuban State Technological
University
Krasnodar, Russia
kubanochka23@yandex.ru

Anastasia Kaloeva
Institute of Food and
Processing Industry
Kuban State Technological
University
Krasnodar, Russia
kaloeva95@mail.ru

Sergey Usatkov
Institute of Fundamental
Sciences
Kuban State Technological
University
Department of Mathematical
and Computer Methods
Kuban State University
Krasnodar, Russia
sv@usatkov.com

Igor Tereshchenko
Institute of Fundamental
Sciences
Kuban State Technological
University
Krasnodar, Russia
tereshchenko57@rambler.ru

Abstract— The aim of the study is the modification of sesame seed proteins on the basis of the complex use of physical methods (treatment with electromagnetic fields of extremely low frequency (EMF ELF) with subsequent thermodenaturation). In the course of the studies, the functional properties of protein products from sesame seeds were determined: fat-holding and fat-emulsifying abilities. The data obtained were analyzed using the MathCAD and Statistica tools. It is established that, in comparison with the traditional technology for the production of protein products from sesame seeds (full-fat flour, protein concentrate, protein isolate), the complex effect, including the processing of EMF ELF at parameters: processing time $T = 30$ min, frequency $\omega = 40$ Hz, current $I = 30$ A, followed by heating, increases the fat-holding ability of full-fat flour.

Keywords—protein products from sesame seeds, full-fat flour, thermodenaturation, extremely low frequency electromagnetic fields.

I. INTRODUCTION

Plant raw materials are the most important source of protein, the deficiency of which is especially acute today. The search for new technologies for the production of protein products is necessary in order to maximize the benefits of plant components, and to obtain proteins with high technical and functional properties. Protein derived from plant products has a lower cost, unlike animal protein.

Irrational consumption of plant raw materials leads to losses in its potential productivity, and therefore, there is an increasing need to study existing technologies for the production of protein from plant raw materials and products of its processing [1, 2].

II. LITERATURE REVIEW

Sesame is a little explored and promising source of protein, since the sum of the essential amino acids in its seeds is higher than in the reference protein, with the bulk of them being amino acids like tyrosine, phenylalanine and tryptophan. Sesame seeds also contain a large amount of unsaturated fatty acids,

including essential ones such as linoleic and linolenic. Sesame oil is present in sesame oil (oxyhydroquinone methyl ester), an active antioxidant that provides high resistance to sesame oil during storage, as well as vitamin E [3].

In order to get the maximum use from the secondary products of oilseeds, it is necessary to solve the issue of the technology for the production of protein products and the modification of the resulting protein products. The most promising group of methods for regulating the functional properties of a protein in practical terms includes physicochemical methods: thermodenaturation, enzymatic modification, complexation of proteins with other substances, and treatment with electromagnetic fields [4, 5].

Thermodenaturation of proteins is widely used to regulate the functional properties of proteins [6]. In most cases, thermodenaturation helps to reduce solubility and other functional properties; therefore, it was considered as not recommended from the standpoint of protein processing in food production. However, interest in protein thermodenaturation increased again due to the discovered possibility of obtaining soluble products with new functional properties, such as the surface properties of the protein, its ability to stabilize emulsions and foams, as well as rheological properties and the ability to form gels [7].

The conducted studies suggest that in biological systems under the influence of electromagnetic fields of low frequencies (EMF LF), various macroscopic phenomena may occur, overlapping by several orders of magnitude any effects of a thermal nature. A characteristic property of such systems during their interaction with EMF LF is a change in

the kinetics and speed of heterogeneous reactions occurring in them, despite the fact that the total energy of such systems in low-frequency magnetic fields, as is known, practically does not change [7, 8, 9].

The aim of the research is the modification of sesame seed proteins based on the integrated use of physical methods (processing with extremely low frequency electromagnetic fields followed by thermodenaturation) to increase the functional properties: fat-holding and fat-emulsifying ability (FHA and FEA).

III. RESEARCH METHODOLOGY

The object of the study was selected protein product from sesame seeds - full-fat flour (FFF) with different oil content, which are grinded seeds without separation of the shells. This

protein product contains from 23 % to 25 % protein, and can be directly used as an enriching additive in the preparation of flour culinary and confectionery products.

Modification of the functional properties of protein products from sesame seeds based on the complex use of physical methods – thermodenaturation and treatment with extremely low frequency electromagnetic fields (EMF ELF) was carried out according to the technology presented in Figure 1.

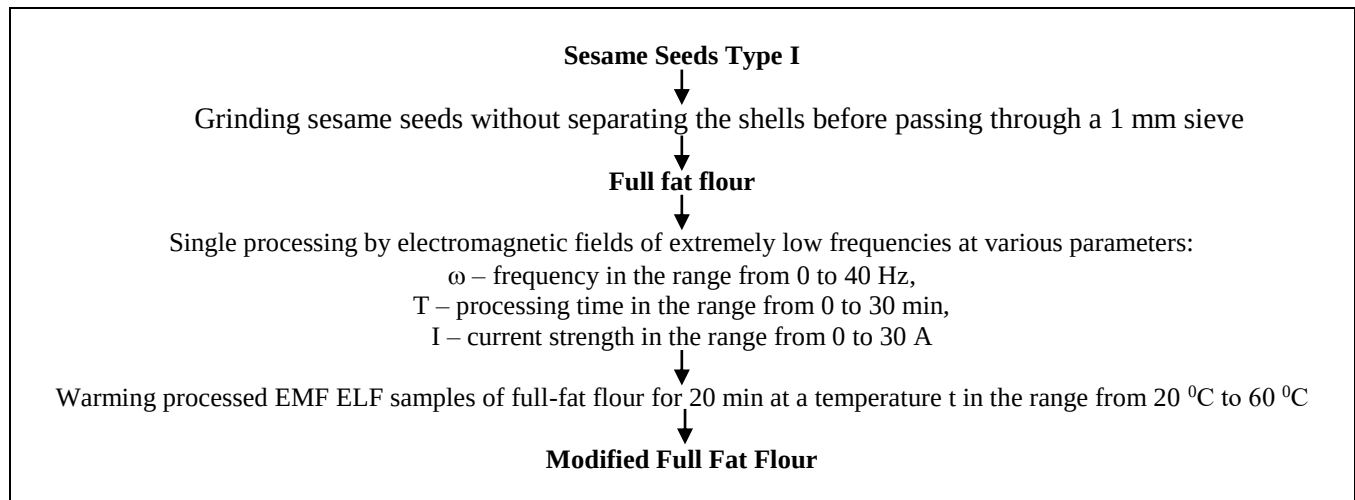


Fig. 1. Complex modification of protein products from sesame seeds by physical methods

Processing protein products from sesame seeds EMF ELF was carried out using an experimental setup [10].

The experiment evaluating the effect of EMF ELF processing parameters with subsequent thermo modification on the functional properties of full-fat flour was carried out according to three-level four-factor full plan. $P(\omega, I, T, t)$ is

$$P(\omega, T, I, t) = \left(a_0 + a_1 \cdot \frac{t}{t_{max}} + a_2 \cdot \left(\frac{t}{t_{max}} \right)^2 \right) + \left(b_0 + b_1 \cdot \frac{t}{t_{max}} + b_2 \cdot \left(\frac{t}{t_{max}} \right)^2 \right) \cdot \left(\frac{\omega}{\omega_{max}} \cdot \frac{T}{T_{max}} \cdot \frac{I}{I_{max}} \right) + \left(c_0 + c_1 \cdot \frac{t}{t_{max}} - c_2 \cdot \left(\frac{t}{t_{max}} \right)^2 \right) \cdot \left(\frac{\omega}{\omega_{max}} \cdot \frac{T}{T_{max}} \cdot \frac{I}{I_{max}} \right)^2 \quad (1)$$

where $a_0, a_1, a_2, b_0, b_1, b_2, c_0, c_1, c_2$ – are the regression coefficients;

ω – factor 1, frequency, Hz;

T – factor 2, processing time, min;

I – factor 3, current strength, A;

t – factor 4, temperature, °C.

Each of listed factors has three levels of variation.

1) Frequency Variation Levels, ω : ω_0 = level -1 = 0 Hz; ω_{av} = level 0 = 20 Hz; ω_{max} = level +1 = 40 Hz.

designated as the desired dependence $P = FHA, P = FEA$ from T, I, t . The simplest quadratic model capable of displaying extremes was used. This is a quadratic model of factors: temperature and the combined factor formed by the product of three initial parameters (1).

2) Levels of variation in processing time, T : T_0 = level -1 = 0 min; T_{av} = level 0 = 15 min; T_{max} = level +1 = 30 min.

3) Current Variation Levels, I : I_0 = level -1 = 0 A; I_{av} = level 0 = 15 A; I_{max} = level +1 = 30 A.

4) Temperature Variation Levels, t : t_0 = level -1 = 20 °C; t_{av} = level 0 = 40 °C; t_{max} = level +1 = 60 °C.

The matrix of a three-level four-factor full plan, taking into account the zeroing of the combined factor with at least one zero parameter of the EMF ELF, is presented in Table 1.

TABLE I. MATRIX FOUR-FACTOR THREE-LEVEL OVERALL PLAN

№ test	Oiliness, M, %	Temperature T, °C	Processing time, T, min	Frequency, ω , Hz	Current I, A	T/T _{max}	ω/ω_{max}	I/I _{max}	t/t _{max}
1.	X ₁	t _{max}	T ₀	ω_0	I ₀	0	0	0	1
2.	X ₁	t _{av}	T ₀	ω_0	I ₀	0	0	0	0.666666667
3.	X ₁	t ₀	T ₀	ω_0	I ₀	0	0	0	0.333333333
4.	X ₁	t _{max}	T ₀	ω_{av}	I _{av}	0	0.5	0.5	1
5.	X ₁	t _{av}	T ₀	ω_{av}	I _{max}	0	1	1	0.666666667
6.	X ₁	t ₀	T ₀	ω_{max}	I _{cp}	0	1	0.5	0.333333333
7.	X ₁	t _{max}	T _{av}	ω_0	I _{av}	0.5	1	0	1
8.	X ₁	t _{av}	T _{max}	ω_0	I _{max}	0.5	0.5	0	0.666666667
9.	X ₁	t ₀	T _{av}	ω_0	I _{max}	1	0.5	0	0.333333333
10.	X ₁	t _{max}	T _{av}	ω_{av}	I ₀	0.5	0	0.5	1
11.	X ₁	t _{av}	T _{av}	ω_{max}	I ₀	1	0	0.5	0.666666667
12.	X ₁	t ₀	T _{max}	ω_{av}	I ₀	0.5	0	1	0.333333333
13.	X ₁	t ₀	T _{av}	ω_{av}	I _{av}	0.5	0.5	0.5	0.333333333
14.	X ₁	t ₀	T _{av}	ω_{av}	I _{max}	0.5	0.5	1	0.333333333
15.	X ₁	t ₀	T _{max}	ω_{av}	I _{av}	1	0.5	0.5	0.333333333
16.	X ₁	t ₀	T _{max}	ω_{av}	I _{max}	1	0.5	1	0.333333333
17.	X ₁	t ₀	T _{av}	ω_{max}	I _{av}	0.5	1	0.5	0.333333333
18.	X ₁	t ₀	T _{av}	ω_{max}	I _{max}	0.5	1	1	0.333333333
19.	X ₁	t ₀	T _{max}	ω_{max}	I _{av}	1	1	0.5	0.333333333
20.	X ₁	t ₀	T _{max}	ω_{max}	I _{max}	1	1	1	0.333333333
21.	X ₁	t _{av}	T _{av}	ω_{av}	I _{av}	0.5	0.5	0.5	0.666666667
22.	X ₁	t _{av}	T _{av}	ω_{av}	I _{max}	0.5	0.5	1	0.666666667
23.	X ₁	t _{av}	T _{max}	ω_{av}	I _{av}	1	0.5	0.5	0.666666667
24.	X ₁	t _{av}	T _{max}	ω_{av}	I _{max}	1	0.5	1	0.666666667
25.	X ₁	t _{av}	T _{av}	ω_{max}	I _{av}	0.5	1	0.5	0.666666667
26.	X ₁	t _{av}	T _{av}	ω_{max}	I _{max}	0.5	1	1	0.666666667
27.	X ₁	t _{av}	T _{max}	ω_{max}	I _{cp}	1	1	0.5	0.666666667
28.	X ₁	t _{av}	T _{max}	ω_{max}	I _{max}	1	1	1	0.666666667
29.	X ₁	t _{max}	T _{av}	ω_{av}	I _{av}	0.5	0.5	0.5	1
30.	X ₁	t _{max}	T _{av}	ω_{av}	I _{max}	0.5	0.5	1	1
31.	X ₁	t _{max}	T _{max}	ω_{av}	I _{av}	1	0.5	0.5	1
32.	X ₁	t _{max}	T _{max}	ω_{av}	I _{max}	1	0.5	1	1
33.	X ₁	t _{max}	T _{av}	ω_{max}	I _{av}	0.5	1	0.5	1
34.	X ₁	t _{max}	T _{av}	ω_{max}	I _{max}	0.5	1	1	1
35.	X ₁	t _{max}	T _{max}	ω_{max}	I _{av}	1	1	0.5	1
36.	X ₁	t _{max}	T _{max}	ω_{max}	I _{max}	1	1	1	1

IV. RESULTS

The calculation of the obtained experimental data was carried out using mathematical tools MathCAD and Statistica.

To find the effective parameters of the complex processing, the functional properties of the full-fat flour of the modified EMF ELF with the subsequent thermodenaturation were determined (table 2).

TABLE II. THE EFFECT OF COMPLEX PROCESSING OF EMF ELF AND THERMODENATURATION ON THE FUNCTIONAL PROPERTIES OF FULL-FAT FLOUR

№ п/п	FHA, %	FEA, %	O, %	t, °C	T _{pro} min	ω , Hz	I, A	T/T _{max}	ω/ω_{max}	I/I _{max}	t/t _{mac}
1.	163.98	58	59.5	60	0	0	0	0	0	0	1
2.	158.91	63.64	59.5	40	0	0	0	0	0	0	0.666666667
3.	184.5	60	59.5	20	0	0	0	0	0	0	0.333333333
4.	163.98	58	59.5	60	0	20	15	0	0.5	0.5	1
5.	158.91	63.64	59.5	40	0	20	30	0	0.5	1	0.666666667
6.	184.5	60	59.5	20	0	40	15	0	1	0.5	0.333333333
7.	163.98	58	59.5	60	15	0	15	0.5	0	0.5	1
8.	158.91	63.64	59.5	40	30	0	30	1	0	1	0.666666667
9.	184.5	60	59.5	20	15	0	30	0.5	0	1	0.333333333
10.	163.98	58	59.5	60	15	20	0	0.5	0.5	0	1
11.	158.91	63.64	59.5	40	15	40	0	0.5	1	0	0.666666667
12.	184.5	60	59.5	20	30	20	0	1	0.5	0	0.333333333
13.	195.45	60	59.5	20	15	20	15	0.5	0.5	0.5	0.333333333
14.	210.22	62.2	59.5	20	15	20	30	0.5	0.5	1	0.333333333
15.	201.7	57.8	59.5	20	30	20	15	1	0.5	0.5	0.333333333
16.	202.45	58.1	59.5	20	30	20	30	1	0.5	1	0.333333333
17.	223.65	60	59.5	20	15	40	15	0.5	1	0.5	0.333333333
18.	187.22	59.1	59.5	20	15	40	30	0.5	1	1	0.333333333
19.	201.41	57.8	59.5	20	30	40	15	1	1	0.5	0.333333333
20.	184.63	61	59.5	20	30	40	30	1	1	1	0.333333333
21.	187.2	59.09	59.5	40	15	20	15	0.5	0.5	0.5	0.666666667

№ п/п	FHA, %	FEA, %	O, %	t, °C	T _{pro} min	ω, Hz	I, A	T/T _{max}	ω/ω _{max}	I/I _{max}	t/t _{mac}
22.	177.2	58.7	59.5	40	15	20	30	0.5	0.5	1	0.666666667
23.	182.4	56.82	59.5	40	30	20	15	1	0.5	0.5	0.666666667
24.	185	56.82	59.5	40	30	20	30	1	0.5	1	0.666666667
25.	196.3	56.82	59.5	40	15	40	15	0.5	1	0.5	0.666666667
26.	195.1	64.44	59.5	40	15	40	30	0.5	1	1	0.666666667
27.	184.4	60	59.5	40	30	40	15	1	1	0.5	0.666666667
28.	175.9	59.52	59.5	40	30	40	30	1	1	1	0.666666667
29.	217.87	54.55	59.5	60	15	20	15	0.5	0.5	0.5	1
30.	187.02	58.14	59.5	60	15	20	30	0.5	0.5	1	1
31.	193.02	57.14	59.5	60	30	20	15	1	0.5	0.5	1
32.	200.47	62.79	59.5	60	30	20	30	1	0.5	1	1
33.	171.35	59.09	59.5	60	15	40	15	0.5	1	0.5	1
34.	179.25	59.09	59.5	60	15	40	30	0.5	1	1	1
35.	165.85	59.09	59.5	60	30	40	15	1	1	0.5	1
36.	176.96	64.29	59.5	60	30	40	30	1	1	1	1

A regression analysis of experimental data was carried out to obtain the dependences of the functional properties (FHA,

FEA) (2, 3) of FFF on temperature (t, °C), oil content (M, %) and EMF ELF processing parameters (ω, Hz, I, A, T, min).

$$FHA = (247,558 + (-232,177) \cdot t + 155,261 \cdot t^2) + (-29,210 + 427,735 \cdot t + (-331,518) \cdot t^2) \cdot X + (-24,389 + (-244,724) \cdot t + 204,521 \cdot t^2) \cdot X^2 \quad (2)$$

$$FEA = (50,211 + 41,659 \cdot t + (-34,439) \cdot t^2) + (29,852 + (-145,929) \cdot t + 118,123 \cdot t^2) \cdot X + (-15,062 + 85,006 \cdot t + (-64,776) \cdot t^2) \cdot X^2 \quad (3)$$

where

$$t = \frac{t}{t_{max}}$$

$$X = \frac{\omega}{\omega_{max}} \cdot \frac{T}{T_{max}} \cdot \frac{I}{I_{max}}$$

The correlation index of the functional properties of the test product is presented in table 3.

TABLE III. THE CORRELATION INDEX OF THE FUNCTIONAL PROPERTIES OF FFF

Name of functional property	Correlation index, R
FHAC	0.76
FEA	0.70

The available values are entered in Statistica, and the values shown in table 4 are obtained.

TABLE IV. REGRESSION COEFFICIENTS FOR FHA AND FEA

Coefficient Designations	Name of functional properties			
	FHA		FEA	
	Regression Coefficients	Significance Level	Regression Coefficients	Significance Level
a0	247.558	0.0	50.211	0.0
a1	-232.177	0.01	41.659	0.0
a2	155.261	0.02	-34.439	0.0
b0	-29.210	0.85	29.852	0.2
b1	427.735	0.40	-145.929	0.1
b2	-331.518	0.38	118.123	0.1
c0	-24.389	0.88	-15.062	0.6
c1	-244.724	0.65	85.006	0.3
c2	204.521	0.61	-64.776	0.3

The available values are entered in Statistica, and the values shown in table 3 are obtained.

The optimization problem is set:

$$FHA(t, X) \rightarrow \max, FEA(t, X) \rightarrow \max. \quad (4)$$

under conditions

$$20 \leq t \leq 60; 0 \leq \omega \leq 40; 0 \leq T \leq 30; 0 \leq I \leq 30 \quad (5)$$

It is required to determine the values of temperature (t, °C) and oil content (M, %) at which conditions (4) and (5) are satisfied.

The problem (4) and (5) of vector optimization was solved by means of the MathCAD v.15 package by linear convolution of criteria and mathematical programming

methods. A linear weighted convolution of criteria K was applied, normalized to the maximum values of each of the criteria separately. By maximizing K, we achieve a consistent maximization of all three criteria (FHA, FEA) (6).

$$K(t, X) = 100 \cdot \frac{\frac{FHA(t, X)}{FHA_{max}} + \frac{FEA(t, X)}{FEA_{max}}}{2} \quad (6)$$

where FHA_{max} , FEA_{max} is the maximum possible value of FHA, FEA with restrictions (5), which are presented in table 4.

In MathCAD, a formula for calculating (1) was introduced taking into account the obtained regression coefficients (Table 4) and the maximum possible values of the FHA for FFF were calculated. Similarly, the calculations

of experimental data for FEA FFF from sesame seeds were performed.

As a result of the calculations, the optimal parameters for the complex processing of full-fat flour by physical methods were obtained (Table 5).

TABLE V. OPTIMAL INTEGRATED PROCESSING OPTIONS OF FFF

Name of indicator	Maximum possible indicator values, %	Processing parameters			
		ω, Hz	T, min	I, A	$t, ^\circ\text{C}$
FHA	206.99	30.34	22.75	22.75	20
FEA	64.65	40	30	30	60

Conclusion on the modification of sesame seed protein proteins based on the complex use of physical methods (EMF ELF and thermal modification).

The solution to the optimization problem (4)-(5) for full-fat flour modified by physical methods is presented in table 6.

TABLE VI. MODIFICATION PARAMETERS OF FULL-FAT FLOUR BASED ON THE COMPLEX USE OF PHYSICAL METHODS

Name of indicator	Coefficient t K	Maximum possible indicator values, %	Processing parameters			
			ω, Hz	T, min	I, A	$t, ^\circ\text{C}$
FHA	95.676	206.99	40	30	30	20
FEA		64.65				

V. CONCLUSION

According to the proposed modification of sesame seed protein proteins based on the integrated use of physical methods, it was found that, in comparison with the traditional technology for producing protein products from sesame seeds, the complex effect, including the processing of EMF ELF with subsequent heating, increases the fat-holding ability of full-fat flour (table 7).

TABLE VII. EFFECT OF MODIFICATION ON THE FUNCTIONAL PROPERTIES OF FULL-FAT FLOUR

Technology	Indicator values, %	
	FHA	FEA
Traditional technology	178.84	81.18
Modification (EMF ELF and thermal modification)	206.963	64.65

Experimentally confirmed the effectiveness of the modification of protein products from sesame seeds based on the complex application of a single treatment of EMF ELF with parameters: processing time $T = 30 \text{ min}$, frequency $\omega = 40 \text{ Hz}$, current $I = 30 \text{ A}$, followed by thermodenaturation, which allows to increase the fat-holding ability of full-fat flour.

REFERENCES

- [1] A.N. Paranyan, "Plant proteins and their importance for growth and development", *Setevoy nauchnyj zhurnal OreIGAU (Network Scientific Journal OreIGAU)*, Vol. 4, No. 4-2, pp. 15-20, 2014. (in russ.)
- [2] A. Achouri and J. I. Boye, "Thermal processing, salt and high pressure treatment effects on molecular structure and antigenicity of sesame protein isolate," *Food Research International*, Vol. 53, No. 1, pp. 240-251, 2013. <https://doi.org/10.1016/j.foodres.2013.04.016>
- [3] F. Aslam, S. Iqbal, M. Nasir, A.A. Anjum, P. Swan, and K. Sweazea, "Effect of hydrogenated fat replacement with white sesame seed oil on physical, chemical and nutritional properties of cookies," *Italian Journal of Food Science*, Vol. 30, No. 1, pp. 13-25, 2018.
- [4] E. P. Meleshkina, I. S. Vitol, and G. P. Karpilenko "Modification of vegetable protein of tritcale grains using biotechnological methods," *Khleboпродукты (Bread products)*, No. 5, pp. 62-64, 2016. (in russ.)
- [5] A. N. Kubasova, I. A. Glotova, V. I. Manzhesov, and A. A. Malibekov, "Enzymatic modification of secondary raw materials in the processing of oilseeds," *Aktual'naya biotekhnologiya (Actual biotechnology)*, No. 3 (10), pp. 127-128, 2014. (in russ.)
- [6] D. V. Kompantsev, A. V. Popov, I. M. Privalov, and E. F. Stepanova, "Protein isolates from vegetable raw materials: an overview of the current state and prospects of development of analysis technology of protein isolates from vegetable raw materials," *Current problems of science and education*, No. 1, pp. 58, 2016. (in russ.)
- [7] T. Xiong, W. Xiong, M. Ge, J. Xia, B. Li, and Y. Chen, "Effect of high intensity ultrasound on structure and foaming properties of pea protein isolate," *Food Research International*, Vol. 109, pp. 260-267, 2018. <https://doi.org/10.1016/j.foodres.2018.04.044>
- [8] Y. Pan, D.-W. Sun, and Z. Han, "Applications of electromagnetic fields for nonthermal inactivation of microorganisms in foods: An overview," *Trends in Food Science & Technology*, Vol. 64, pp. 13-22, 2017. <https://doi.org/10.1016/j.tifs.2017.02.014>
- [9] Z. Han, M.-J. Cai, J.-H. Cheng, and D.-W. Sun, "Effects of electric fields and electromagnetic wave on food protein structure and functionality: A review," *Trends in Food Science & Technology*, Vol. 75, pp. 1-9, 2018. <https://doi.org/10.1016/j.tifs.2018.02.017>
- [10] L. V. Liubimova, G. A. Kupin, P. A. Vlasov, and N. A. Bugayets, "Processing electromagnetic field of culinary products for process control microbiological damage," *Ehlektronnyj setevoy politematicheskij zhurnal "Nauchnye trudy KubGTU" (Scientific works of the Kuban State Technological University)*, No. 14, pp. 204-209, 2016.