Prediction model of microbiological and organoleptic indicators of salads during storage with the processing by extremely low frequency electromagnetic fields

Natalia Bugayets[1,*], *Sergey* Usatikov[1,2], *Lyubov* Lyubimova[1], *Igor*Tereshchenko[1], *Azamat* Shantyz[3], and *Peter* Miroshnichenko[4]

[1]Kuban State Technological University, 350072 Krasnodar, Russia
[2]Kuban State University, 350040 Krasnodar, Russia
[3]Kuban State Agrarian University, 350044 Krasnodar, Russia
[4]Krasnodar Research Veterinary Institute, 350004 Krasnodar, Russia

Abstract. The aim of the research is the scientific justification, development and implementation of physical methods for the protection of culinary products from microbiological damage. The effect of the electromagnetic field of extremely low frequency (EMF ELF) on the expiration date of vegetable salads was studied. The effective processing parameters of the EMF ELF treatment of vegetable vinaigrette postponed its expiration date, providing high quality and safety of dishes throughout the storage period.

1 Introduction

The problem of microbiological safety is particularly acute for manufacturers of finished culinary products sold in large volumes in retail chains. Salads and other cold dishes and snacks are not subjected to heat treatment before sale, so without the use of preservative agents they have limited expiration date.

An effective solution to the issues of safety and prolongation of expiration date of salads is “cold pasteurization”, which involves the use of “barriers”, including the regulation of the redox potential, exposure to pressure, radiation, electromagnetic fields, competing microflora, food additives, etc., which slow down the growth and reproduction of microorganisms [1–4].

More and more attention is being paid to developments in the field of bioenergetics and studying the effect on living organisms from electromagnetic and other physical fields with a frequency of wave oscillations from single-figure hertz values to kilohertz ranges.

The effect of a low-frequency electromagnetic field (EMF) on various biological systems is one of the most relevant and actively studied areas in ecology, biology, medicine, veterinary medicine, and the agricultural and food industries. Works appear, which explore the effects of electromagnetic fields on various strains of yeast, bacteria and bacteriophages. In these works, physiological and morphological changes of microorganisms induced by low-frequency (LF) electromagnetic radiation were established [5–9].

The studies present differences in the ranges of exposure of LF EMF to the growth of microorganisms. Extremely low frequency electromagnetic fields (EMF ELF) are energy-saving, environmentally friendly technologies that gently act on the product and guarantee the elimination of the activity of deterioration microorganisms while maintaining the native properties of the product.

The impact of the EMF ELF on the microorganism leads to the reorientation and deformation of liquid-crystal structures (membranes, mitochondria, etc.) under the influence of an electromagnetic field. This is reflected in permeability, which plays an important role in the regulation of biochemical processes and the fulfillment of their biological functions [6] and ensures a reduction in the microbial contamination of raw materials and food products.

Considering the above, we have conducted studies to determine the possibility of using EMF ELF for disinfecting vegetable salads in order to prolong their expiration date.

2 Materials and methods

The object of the research is a salad, which is in high demand in retail chains and at public catering enterprises – vegetable vinaigrette with different recipes, compositions and methods of technological preparation of products, which allows you to make a general picture of the impact of the "barrier" on the presented group of dishes.

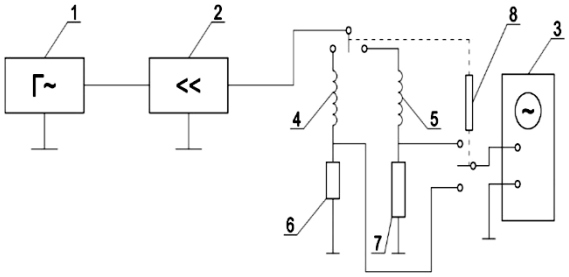
The basis for defining the expiration date of salads is formed by microbiological researche and evaluation of the organoleptic properties of samples taken from finished products during storage.

To determine the technological mode of production of vegetable salads with a prolonged expiration date, the

* Corresponding author: kubanochka23@yandex.ru

number of mesophilic aerobic and optionally anaerobic microorganisms (NMAOAnM) was taken as a controlled indicator of microbiological safety. This indicator characterizes the total content of microorganisms in the product, is used everywhere to assess the quality of the finished product, with the exception of those in the production of which special microbial cultures are used.

Before processing, the samples were portioned to 10 g in separate sealed plastic boxes to exclude secondary semination during material sampling. Prior to storage, a single EMF ELF treatment was performed using an experimental setup, the block diagram of which is shown in Figure 1.



1 – generator; 2 – amplifier; 3 – oscilloscope; 4 – solenoid 1 (large); 5 – solenoid 2 (small); 6 – solenoid current control resistor 1 (1 Ом); 7 – solenoid current control resistor 2 (4 Ом); 8 – solenoid select switch

Fig. 1. The structural scheme of an experimental setup for the processing of salads with EMF ELF

The principle of the experimental setup is as follows. A sinusoidal signal from a low-frequency generator (pos. 1) is modulated by a low-frequency signal using an oscilloscope (pos. 2), in which the amplitude of electromagnetic oscillations is regulated. After the oscilloscope (pos. 3), the signal in the form of electromagnetic oscillations is fed into the power amplifier (pos. 2) through which it enters the solenoids (pos. 4 and 5). In the solenoids (pos.4 and 5), the investigated plant material is placed, which is subjected to electromagnetic oscillations with a given frequency and current strength of the electromagnetic field [5].

Thanks to the solenoid selection switch (pos. 8), the experimental setup provides processing modes of low-frequency amplitude- or frequency-modulated electromagnetic oscillations in the frequency range from 1 to 100 Hz and current from 0.1 to 15 A [5].

Samples were stored until microbial cultures at a temperature of (4±2) °C. The first microbial cultures of the samples were carried out at the beginning of storage to determine the initial bacterial contamination of the samples (P_o). Then microbial cultures were made during storage of the samples studied every 24 hours for 120 hours.

Selection and preparation of samples, the procedure for evaluating the organoleptic characteristics of salads during storage was carried out in accordance with GOST 31986-2012 “Catering services. The method of organoleptic evaluation of the quality of catering products".

The tasting evaluation of the samples was carried out by simultaneous presentation of the coded samples of the investigated product at the end of the expected expiration date (with positive results of laboratory tests), at intervals (24 hours) and similar freshly processed products.

Organoleptic analysis of vegetable salads includes a rating of appearance, texture (consistency), smell and taste using a point scale: 10–9 points – excellent quality, 8–7 points – good quality, 6–5 points – satisfactory quality and 4 points – unsatisfactory quality. The rating assessment of the quality of vegetable salads was carried out as a whole (overall quality level). According to the results of sensory analysis, the quality criterion of organoleptic indicators was calculated for each sample in the range from 0 to 1.0.

To ensure the statistical validity of the results, the independent tasting participants (3 persons) were not aware of the sample codes.

An experiment to evaluate the effect of EMF ELF processing parameters on microbiological and organoleptic indicators of lettuce was carried out according to a 3-factor 3-level plan, for an exponential regression model with a quadratic index in parameters (for NMAOAnM) and a quadratic regression model for organoleptic evaluation. The duration of processing of vegetable vinaigrette with EMF ELF varied in the range from 0 to 30 min (T_{min} = 0, T_{av} = 15 min, T_{max} = 30 min), frequency – from 0 to 40 Hz (ω_{min} = 0, ω_{av} = 20 Hz, ω_{max} = 40 Hz), current strength – from 0 to 30 A (I_{min} = 0, I_{av} = 15 A, I_{max} = 30 A). There are in total 3^3 = 27 combinations of parameters for processing by EMF ELF, but the full plan was reduced due to the necessary zeroing of all parameters T_{min}, ω_{min}, I_{min} with at least one of them zero.

The parameters of regression models for microbiological and organoleptic indicators were calculated by means of the STATISTICA package.

The optimization of the technological regime for microbiological and organoleptic indicators in the processing of EMF ELF with the aim of increasing the implementation period of ready meals was carried out according to the procedure shown in Figure 2.

The optimization problem (and the reduction of the vector criterion to the scalar one) is posed as follows. The available microbiological and organoleptic indicators are given to the objective function – the maximum possible expiration date, with a feasible set defined by inequalities: the upper bound is the normalized safety indicator of NMAOAnM $5{,}0\times10^4$ CFU/g, the lower bound is the acceptable level of organoleptic assessment of 0,6. The objective function is the expiration date, the feasible set – the limitations of the permissible level of the microbiological safety standard according to Customs Union Technical Regulations (CU TR) 021/2011 “On food safety of food products” and the permissible level of organoleptic evaluation. The solution of this problem is implemented by means of mathematical software environment MathCAD.

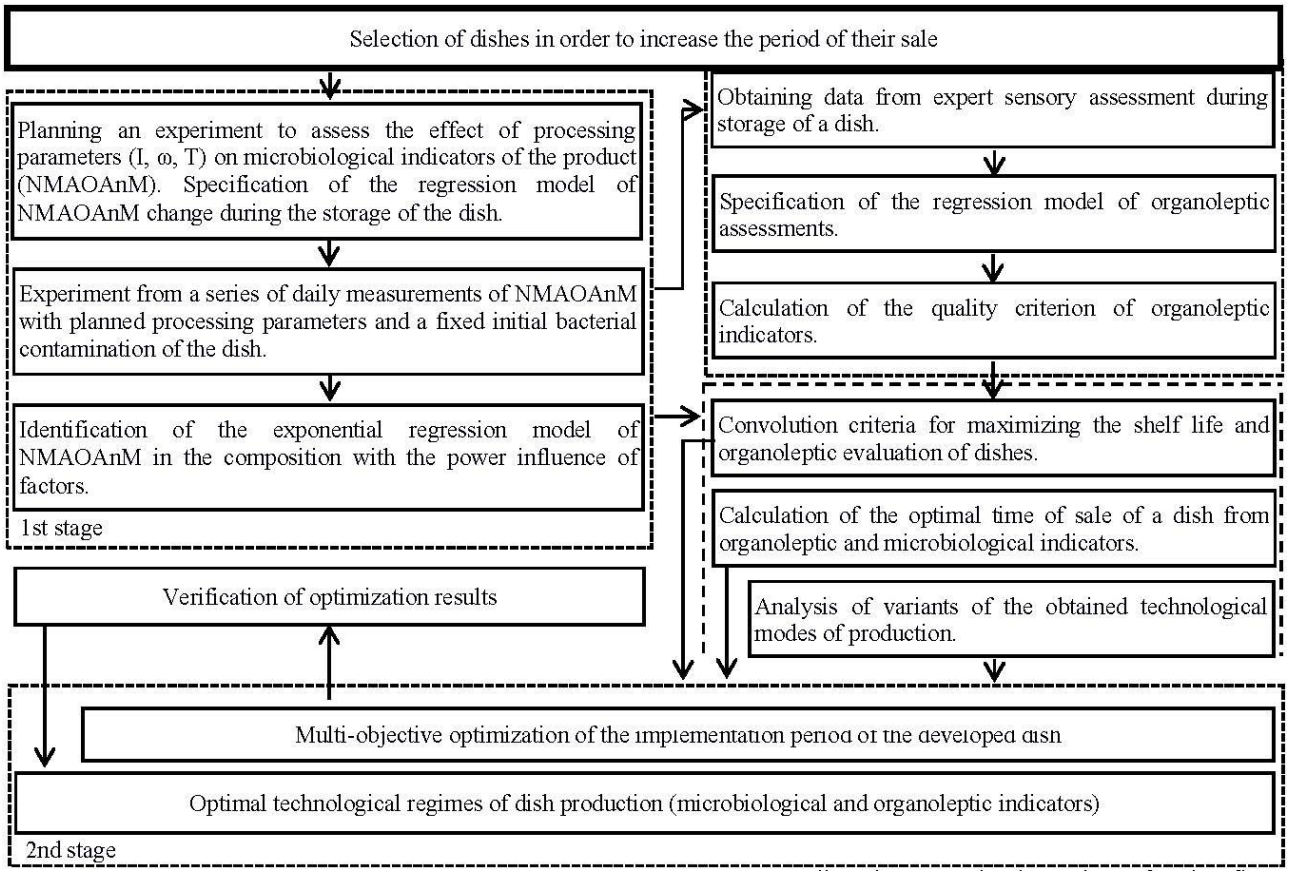


Fig. 2. The method of optimization of technological regime for microbiological (quantity of mesophilic aerobic and facultative anaerobic microorganisms NMAOAnM) and organoleptic indicators in order to increase the implementation period of ready meals (time t): EMF ELF processing (processing time T; processing frequency ω; current during processing I).

Experimental studies were carried out in research laboratories of the Department of Public Catering and Service and the Center for Collective Use of "the Research Center for Food and Chemical Technologies" of the Kuban State Technological University, as well as the Department of Epizootology, Mycology and Veterinary-Sanitary Expertise of the Krasnodar Veterinary Research Institute (separate structural divisions of the Federal State Budgetary Scientific Institution "Krasnodar Research Center for Zootechnics and Veterinary Medicine").

3 Results and discussion

As a result, the technological mode of production of salads with a prolonged expiration date was found optimal in terms of microbiological and organoleptic indicators.

Studies of the effect of the parameters of EMF ELF processing on the expiration date of vegetable vinaigrette were performed in several stages (Figure 2).

To predict the growth dynamics of microflora NMAOAnM, (CFU/g) of salad P = P (t, T, ω, I) depending on the storage time (t, h) and EMF ELF processing parameters (T, min, ω, Hz, I, A) an exponential regression model was used with a quadratic in the parameters indicator, provided that the initial contamination P0 = P (t = 0) of freshly prepared salad is known at the beginning of storage (t = 0 h) before EMF ELF processing. Here: P_0 – the value of NMAOAnM, CFU/g, freshly prepared salad before processing EMF ELF at the beginning of storage (t = 0 h); T – duration of EMF ELF processing, min; ω – frequency of EMF ELF processing, Hz; I – current of EMF ELF processing, A.

To determine the effective parameters of EMF ELF processing, microbiological studies were carried out and the NMAOAnM vegetable vinaigrette samples were taken during storage at a temperature of (4 ± 2) ° C (table 1).

It has been established that the duration and frequency of the processing of EMF ELF have a significant effect on the growth of vegetable vinaigrette microflora [9].

According to the obtained experimental data, the regression growth model KMAFAnM was identified. The regression model parameters are calculated using the STATISTICA package; the correlation index is R = 0.9. For vegetable vinaigrette, growth regression model KMAFAnM from the duration of storage of dish and processing parameters of EMF ELF has the form:

$$P(t,T,\omega,I) = P_0 \cdot \exp\left(-1.3254\left(\frac{T}{30}\right)\left(\frac{\omega}{40}\right)\left(\frac{I}{30}\right)\right) \times$$

$$\times \exp\left(\left[\begin{array}{c} 0.014693 - 0.026889\left(\frac{T}{30}\right)\left(\frac{\omega}{40}\right)\left(\frac{I}{30}\right) + \\ +0.034517\left(\left(\frac{T}{30}\right)\left(\frac{\omega}{40}\right)\left(\frac{I}{30}\right)^2\right) \end{array}\right] t\right) \qquad (1)$$

where the dimensionless arguments $\left(\frac{T}{30}\right)\left(\frac{\omega}{40}\right)\left(\frac{I}{30}\right)$ are normalized by the maximum values of the EMF ELF processing parameters (T_{max} = 30 min, ω_{max} = 40 Hz, I = 30 A).

Table 1. Effect of EMF ELF treatment of salads on microbiological indicators during storage

Processing parameters EMF ELF	Frequency of control					
	Shelf life, h					
	background	24	48	72	96	120
	NMAOAnM, ×10 ^{4} CFU/g					
T_{av} ω_{av} I_{av}	0.75	0.86	0.77	1.40	1.90	2.40
T_{av} ω_{av} I_{max}	0.45	0.49	0.74	0.83	1.80	1.90
T_{max} ω_{av} I_{av}	0.69	0.57	0.74	0.83	0.92	0.90
T_{max} ω_{av} I_{max}	0.61	0.72	1.81	1.22	1.77	3.40
T_{av} ω_{max} I_{av}	1.34	1.52	1.60	1.66	1.70	1.72
T_{av} ω_{max} I_{max}	1.20	1.62	1.73	1.90	2.72	3.10
T_{max} ω_{max} I_{av}	1.72	3.13	3.18	3.70	8.80	11.60
T_{max} ω_{max} I_{max}	1.72	2.05	2.92	3.54	4.63	12.60

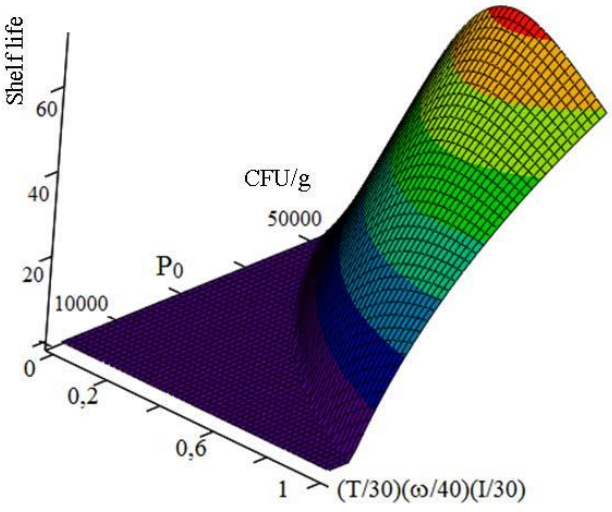
In the process of storing samples of vegetable vinaigrette treated with EMI ELF, a sensory analysis was carried out and the dependence of the assessment of the organoleptic properties of vegetable vinaigrette K_0(t, T, ω, I) on the storage time (t, h) and EMF ELF processing parameters (T, min, ω, Hz, I, A).

According to experimental data, the dependence of the evaluation of the organoleptic properties of vegetable vinaigrette on the storage time and the parameters of EMF ELF processing was established. Despite the slowdown in the growth of microflora, the organoleptic characteristics of samples of vegetable vinaigrette are reduced during storage in relation to freshly produced products.

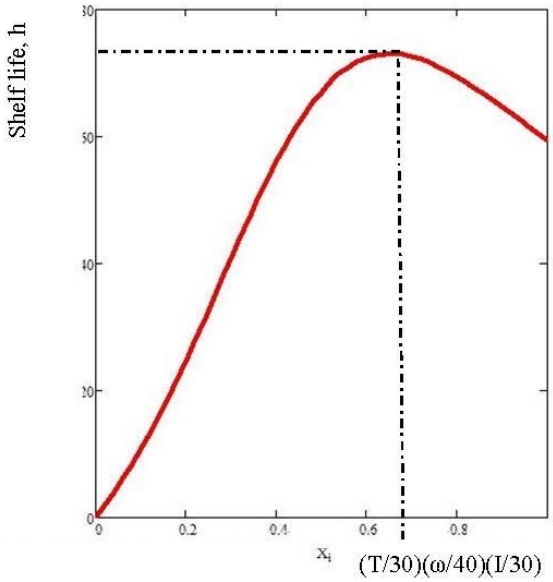
The parameters of the regression model for organoleptic indicators were calculated using the STATISTICA package; the correlation index is R = 0.91. The dependence of the evaluation of organoleptic properties of $K_O(t, T, \omega, I)$ on the duration of storage (t, h) and processing parameters of EMF ELF (T, min, ω, Hz, I, A) has the form:

$$K_O(t,T,\omega,I) = 0.981 - 0.609\left(\frac{t}{216}\right) - 0.035\left(\frac{t}{216}\right)^2 + 0.221\left(\frac{t}{216}\right) + 51.873\left(\frac{T}{30}\right)\left(\frac{\omega}{40}\right)\left(\frac{I}{30}\right) - 05.976\left(\frac{T}{30}\right)^2\left(\frac{\omega}{40}\right)^2\left(\frac{I}{30}\right)^2 \quad (2)$$

The obtained dependences (1) and (2) allow us to predict the expiration date of the vegetable salad. The optimization problem was solved using the MathCAD package; the maximum expiration date of 73 h of vegetable vinaigrette during the processing of EMF ELF was established (figure 3).



a – depending on the initial contamination P_0



b – with initial contamination $P_0 = 5\times10^4$ CFU/g – limiting the permissible level of the microbiological safety standard according to CU TR 021/2011

Fig. 3. Influence of EMF ELF processing parameters on the shelf life of vegetable vinaigrette

The optimal parameters of the technological mode are: processing time T = 26 min, frequency ω = 35 Hz and current I = 26 A EMF ELF extending the expiration date of vegetable vinaigrette from 12 hours (according to SanPiN 2.3.2.1324) to 73 h for a normalized value of the initial contamination ($P_0 = 5\times10^4$ CFU/g).

The value of the criterion for organoleptic evaluation is 0.84, which is above the permissible level of 0.6.

The final stage of optimization is the verification [10] of the obtained regression models for microbiological and organoleptic indicators of vegetable vinaigrette during storage.

The results of the verification of regression models for microbiological and organoleptic indicators confirm the established expiration date of the vegetable vinaigrette as 73 h.

4 Conclusion

According to the proposed model of optimization for the technological mode of production of vegetable salads, the parameters of EMF ELF processing T = 26 min, ω = 35 Hz, I = 26 A were determined, extending the expiration date set by SanPiN 2.3.2.1324-03 "Hygienic requirements for expiration date and storage conditions of food products" from 12 hours to 73 hours, providing high organoleptic quality and safety of dishes throughout the expiration date.

The use of physical methods to protect culinary products from microbiological damage opens wide opportunities for modernization of technological processes to prolong sale periods of finished production with preservation of its high quality.

References

1. T. Danilchuk, V. Ganina, Foods and Raw Materials **6(2)**, 305–313 (2018)
2. R.T. Timakova, S.L. Tikhonov, N.V. Tikhonova, I.F. Gorlov, Foods and Raw Mater. **6(1)**, 120–127 (2018)
3. P. Del Valle, M.R. Garcia-Armesto, J. Campos et al., J. of food and nutrition res. **57(1)**, 76–86 (2018)
4. A. Kyung-A, J. Yunhee, M.S. Arshad, K. Gui-Ran, C. Jo, K. Joong-Ho, Korean J. for food sci. of animal res. **37(2)**, 297–304 (2017)
5. T.V. Pershakova, G.A. Kupin, L.V. Mihaylyuta et al., J. of Pharmaceut. Sci. and Res. **10(8)**, 1897–10901 (2018)
6. G.P. Il'chenko, M.G. Baryshev, E.E. Tekutskaya et al., Measurement Techniques **60(6)**, 632–637 (2017)
7. G.I. Kasyanov, I.E. Syazin, A.V. Grachev, T.N. Davidenko, Food Sci. and Technol. **24(3)**, 88–93 (2013)
8. M.S. Koneva, N.A. Bugayets, O.V. Rudenko et al., J. of Phys.: Conf. Ser. **1015**, 032018, (2018) DOI:10.1088/1742-6596/1015/3/032018
9. L.V. Lyubimova, N.A. Bugayets, G.A. Kupin, I.A. Bugayets, Sci. of Kuban **1**, 53–58 (2017)
10. J. Szczawinski, M.E. Szczawinska, A. Lobacz et al., J. of veter. res. **61(1)**, 45–51 (2017)