UDC 579 : [633.1 631.17]

INFLUENCE OF TREATMENT OF WHEAT GRAIN WITH AN EXTREMELY LOW FREQUENCY ELECTROMAGNETIC FIELD ON ITS MICROBIOTA

https:// doi.org/ 10.15673/fst.v19i4.3297

Yu. Kovra[1], Chemist of the First Category of Food Safety Laboratory
B. Zhukov[1], Deputy Head of the Molecular Genetics and Microbiology Laboratory
G. Stankevych[2], Doctor of Technical Science, Professor
[1]Testing Center of Foreign Enterprise "SGS Ukraine"
103, Chornomorskogo Kozatstva Str., Odesa, Ukraine, 65003
[2]Department of Grain and Feed Technology
Odesa National University of Technology
112, Kanatna Str., Odesa, Ukraine, 65039

Correspondence:
G. Stankevych
E-mail: georgii.stn@gmail.com

Cite as Vancouver style citation

Kovra Yu., Zhukov B., Stankevych G. Influence of treatment of wheat grain with an extremely low frequency electromagnetic field on its microbiota . Food Science and Technology. 2025;19(4):18-28. https:// doi.org/ 10.15673/fst.v19i4.3297

Цитування згідно ДСТУ 8302:2015

Kovra Yu., Zhukov B., Stankevych G. Influence of treatment of wheat grain with an extremely low frequency electromagnetic field on its microbiota// Food Science and Technology. 2025. Vol. 19, Issue 4. P. 18-28
https:// doi.org/ 10.15673/fst.v19i4.3297

Abstract. The aim of the study was to treat contaminated wheat grain samples with an extremely low frequency (ELF) electromagnetic field (EMF) to reduce its microbiological contamination, which will help improve the quality of the grain and its storage period. After treatment, the total number of mold and yeast fungi in the treated and control grain samples was determined, the dynamics of contamination was analyzed relative to the initial value and the selected EMF frequency range, and a statistical analysis of the relationship between the intensity of grain sample treatment and their contamination was performed. The study established the possibility of reducing the contamination of wheat grain with phytopathogenic microorganisms *Cladosporium spp., Alternaria spp., Helminthosporium spp., Fusarium spp.,* and *Nigrospora spp.,* by treating the grain infected with them with EMF in the frequency range of 10–30 Hz. The highest effect is achieved at an EMF frequency of 30 Hz. It was shown that the treatment of wheat grain with EMF at a frequency of 30 Hz allowed to significantly reduce the contamination of *Cladosporium spp.,* and *Fusarium spp.,* – to 1.75% and 3.92% of the initial value, respectively. The contamination of microorganisms *Alternaria spp.,* and *Helminthosporium spp.,* after grain treatment at a frequency of 30 Hz was slightly higher and amounted to 5.15% and 9.97% of the initial value, respectively. In relation to *Nigrospora spp.,* the disinfection efficiency after wheat grain treatment was the lowest – the initial contamination value decreased to 12.50% of the initial value. It was found that the highest reduction in the concentration of mold fungi was provided by the treatment of wheat grain with EMF at a frequency of 30 Hz, which allowed to reduce the total mold load by 96.84% of the initial value. The greatest efficiency in reducing the concentration of yeast fungi was shown by the treatment of grain with EMF at a frequency of 16 Hz, which allowed to reduce the total yeast load by 95.76% of the initial value. Considering the quantitative indicators of the concentration of microorganisms, the general conclusion indicates the ability of electromagnetic treatment to significantly reduce the mycological load on wheat grain. However, the studied modes of grain treatment with EMF cause the complete destruction of viable microorganisms and require further more extensive study.

Key words: wheat grain, extremely low frequency electromagnetic field, electromagnetic field treatment, microbiological indicators, storage, correlation and regression analysis

Introduction. Formulation of the problem

It is known that grain mass is a set of interconnected components of the main crop grain, impurities, microorganisms, insects and air in the intergranular spaces. The main factors on which the state of the grain mass depends are humidity, temperature and access of oxygen to the grain. The stability and quality of grain are significantly affected by mechanical and waste impurities, microorganisms, insects, mites, air [1].

Microorganisms are an inevitable companion of the grain mass, its component part. Under appropriate conditions, they significantly affect the state and quality of the grain, which is manifested in mold and warming of the grain. Bacterial spores, if consumed, can cause serious disruptions in the functioning of the immune system, gastrointestinal tract, respiratory organs, nervous system [2], so it is important to control this indicator.

For grain storage, producers use various methods. The literature includes storage of grain in polymer grain sleeves [3], using cooling [4], inert gas [5], ozone treatment [6], using high-frequency electromagnetic treatment (2.45 GHz) [7,8], etc.

At the same time, it is known that in the technology of improving the quality of agricultural products, methods of processing with a low-frequency (LF) electromagnetic field (EMF), namely the EMF range of extremely low frequencies (ELF) – from 3 to 30 Hz, can be used. This method is inexpensive and environmentally friendly [9], described in a review article by scientists from Serbia and Romania. It provides literature data on the classification of EMF and the results of the experiments. The researchers based on the use of the RIES (resonant pulsed electromagnetic stimulation) method, developed at the Faculty of Agriculture of the University of Novi Sad, have drawn conclusions about the impact of EMF ELF on various types of agricultural crops. The authors explain the attention paid to the impact of EMF in agriculture by the possibility of influencing plant growth and, thus, obtaining significant economic effects.

Analysis of recent research and publications

The first practical studies of the use of magnetic fields were conducted in the 1970s in southern Alberta (Canada). Studies of the effect of magnetic fields on seeds and yields of barley, wheat and oats showed that they did not affect oat yields, but increased barley yields in most experiments with winter and spring wheat. The time of seed treatment, the strength of the magnetic field and the type of processing equipment did not have a significant effect on plant growth and grain yields of the studied crops [10].

The literature also shows that over the past two decades, the number of studies aimed at studying the effects of EMF on plants has increased significantly [11]. Most often, these studies concern the effect of EMF on biochemical processes during grain germination and activation of seed germination of various crops [12].

Thus, in the article [13], Polish experts present the results of studying the effect of LF EMF treatment (16 Hz and 50 Hz) on the germination of seeds of various crops, including wheat. They concluded that variable LF EMF (16 Hz) can be used as a method of post-harvest treatment to improve the strength of seeds of various plant species, as a method recommended for seeds that germinate in adverse environmental conditions or seeds of low quality.

A little later, other Polish experts concluded that as a result of pre-sowing treatment, EMF seed stimulation can have a positive, but mainly temporary and unstable effect on the germination percentage, growth rate and germination rate [14].

The implementation of these works is related to pre-sowing treatment. Experts also indicate that the potential of EMF treatment capabilities is not used in Ukrainian agriculture [15]. Currently, the equipment based on the properties of the magnetic field is practically used in post-harvest processing and storage in our country only in separators that clean grain from metal impurities [16].

A significant number of studies in the field of microwave processing of materials, including grains, were conducted by Odesa scientists [17]. Also, in addition to microwave processing, group of Odesa scientists (L. Kalinin, I. Boshkova, G. Panchenko, S. Kolomeychuk) conducted studies of the impact of low-frequency processing on seeds of seed purpose. It was established that the impact of LF EMF on plant seeds during their dormancy period leads to significant changes in the physiology of seeds during germination. Changes at the physiological level in germinating seeds depend not only on the frequency of the external EMF and its energy characteristics, but also on the seed variety. Both LF and high frequency (HF) EMF are capable of leading to the effect of seed biostimulation, but the mechanisms of its occurrence are different in nature.

Another group of Ukrainian scientists conducted a study of the influence of EMF on the quality of grain products [18]. They investigated the influence of hydrothermal treatment and the time of electromagnetic irradiation on the yield and quality of rolled whole-grain groats from Emmer wheat. At the same time, a significant influence of EMF on the quality of the product was established. Thus, the use of optimal grain processing parameters (moistening by 1.0%, EMF irradiation for 80–100 s) ensures the yield of high-quality whole-grain rolled groats of 91.7–92.3% with a culinary score of 7.3 points.

Pakistani scientists studied the stimulating effect of magnetized seeds and water on the germination of wheat seeds with low moisture content and growth energy (45%). They concluded that wheat seeds with low growth energy can be stimulated with magnetized water [19]. The literature contains interesting studies conducted by a group of scientists from the O.Ya. Usykov Institute of Radiophysics and Electronics of the National Academy of Sciences of Ukraine and the Mechnikov Institute of Microbiology and Immunology of the National Academy of Medical Sciences of Ukraine [20], which indicate that as a result of direct and indirect irradiation of plant seeds and strains of pathogenic corynebacteria with low-intensity EMF, a nonspecific effect is observed on the indicators of their biological activity. For plant seeds, this is manifested in a change in the germination energy of the average root length and in a decrease in the stability of results in batches under certain exposure modes, especially when treated with fractal noise. For bacterial cultures, it is a change in their growth qualities. Thus, it becomes possible to purposefully modify indicators of biological activity in the form of external electromagnetic influence.

The microbiological condition of grain is very important, as microbial spoilage before and after the harvest is considered one of the main factors of crop loss worldwide. According to the researchers' publication [21], approximately 15% of all grain crops worldwide are lost due to microbial pests. It is indicated that appropriate post-harvest processing of the crop before and during storage is as important as pre-harvest strategies to prevent microbial spoilage. However, even the best management practices cannot eliminate the risk of contamination. Due to the constant and ubiquitous presence of microorganisms and fungal spores in the environment, cereals always carry some microbial load during the harvest. In addition, climatic conditions such as temperature and humidity, which are not controlled by humans, can be crucial for mold contamination. Even under optimal processing conditions, it is unlikely that cereals can be decontaminated from all natural spoilage organisms by a single treatment. The authors consider different processing methods, including electromagnetic fields, and conclude that further research should focus on understanding and optimizing the synergistic effects that can be achieved by combined processing methods. Only then will it be possible to produce products that meet the highest standards of quality and food safety. Also, according to the results of [22], the magnetic field can be a good alternative in the fight against pests that may be present in stored grain. The magnetic field can protect grain from pest infestation during long storage periods without affecting the germination percentage or degrading its quality.

Among the existing methods and modes of grain EMF processing, in recent years, more and more attention has been paid to the use of EMF ELF, which has a number of advantages. It is close to the Earth's geomagnetic field [23], which makes it safer, it is found in the processes of living beings, it is characterized by lower electricity consumption compared to other ranges of EMF, grain processing does not lead to its heating, etc.

Due to the fact that the effectiveness of EMF action on living organisms depends on the frequency (or the parameter associated with it – wavelength) and the radiation dose, the direction of studying the influence of low-frequency EMF on the microbiological state of grain is interesting. Studies conducted at ONTU in this direction also showed that the treatment of wheat grain with EMF ELF leads to the suppression and reduction of the number of microorganisms. To significantly reduce the number of microorganisms, grain EMF processing is recommended to be carried out at a frequency of 30 Hz [24].

The EMF processing method should not be considered as a method that will replace other modern methods. According to modern experts in the field of food research, developments in improving post-harvest processing and storage researchers should focus on understanding and optimizing the synergistic effects that can be achieved using combined processing methods. Only then will it be possible to produce products that meet the highest standards of quality and food safety [25]. Based on this, the EMF ELF processing method should be further considered (studied) while using other effective methods.

It is also indicated by the experts that although EMF ELF is a weak stressor, it can act synergistically with other inactivating agents and, therefore, can be considered as an alternative method for industrial application [26].

The research, made by the specialists also shows that EMF ELF is a potential tool that can be used to overcome bacterial contamination and infections [27].

New publications in the literature also indicate the potential applicability of EMF in biotechnological processes. It has been shown, in particular, that the EMF causes various stimulating or inhibitory effects on microorganisms [28]. The growing interest in this topic over the years has led to numerous scientific discoveries indicating the potential applicability of EMF in biotechnological processes.

It should also be added that the EMF ELF treatment method does not require the use of harmful substances and is an environmentally friendly method. It follows from the reviewed literature that studies of the impact of EMF ELF on the storage processes of wheat grain and their impact on microbiological indicators that have a significant impact on the shelf life are fragmentary or absent, therefore it is relevant to determine the impact of EMF in this range on the microbiological indicators of wheat grain during its storage.

Purpose and objectives of the study. The purpose of the study was to establish the effect of EMF ELF treatment of wheat grain on its microbiological indicators, which will contribute to improving the quality of the grain and its storage period.

To achieve the goal, the following tasks were set:

1) to perform the control check and prepared contaminated wheat samples with EMF at frequencies of 10–30 Hz and determine the total number of mold and yeast fungi in the studied grain samples and give them an assessment;

2) to investigate the dynamics of contamination relative to the initial value depending on the levels of EMF ELF treatment;

3) to conduct a regression analysis of the relationship between the intensity of grain sample treatment and their contamination;

4) to determine the feasibility of treatment.

Research materials and methods

The study was conducted from November 2023 to May 2024 in the laboratories of ONTU and FE of "SGS Ukraine". For the research, grain wheat of the Odessa Ukrainka variety of the 2023 harvest was used, from which control and contaminated grain samples were prepared, which were subsequently treated with EMF with frequencies of 10–30 Hz.

Microbiological studies were conducted under aseptic conditions. Samples were analyzed in three parallels, accompanied by sterility control and negative processing control.

The following equipment was used in the research: Sartorius scales "CPA225D"; Eppendorff dispenser "Eppendorf 100–1000 mkl"; Goryaev chamber "2-grid chamber"; Shott ionometer "Lab850"; Leica microscope "DM500"; Memmert thermostat "IN160"; centrifuge "260/R/RH".

Method of wheat grain processing by EMF ELF. Wheat grain processing was carried out on an experimental installation developed at ONTU, which is described in articles [24,25]. The installation consists of a grain container, which is inserted into a polymer pipe with a solenoid coil wound on it, a generator of electromagnetic oscillations GZ-112/1 and a LF power amplifier. The generator output signal was set in the form of a sinusoid and controlled by an oscilloscope C1-78. The devices were interconnected in the required sequence by cables. The required value of magnetic induction of 10 mT was ensured by stabilizing the voltage at the level of 3.6 V. For this, before the start of each experiment on grain processing, the power regulator of the LF amplifier was set to the required voltage value, which was controlled by a universal (combined) digital voltmeter B7-38. The duration of grain processing was 6 min.

The determination of quality indicators of processed and unprocessed wheat grain was carried out using the methods described below.

Method for determining contamination. Determination of changes in surface contamination of wheat grain. The study consists in washing away characteristic formations of phytopathogenic fungi (conidia, spores, etc.) from the surface of grains with their subsequent sedimentation by centrifugation. The calculation is carried out by microscopy of sediment preparations and counting in the Goryaev chamber. The method is implemented in accordance with DSTU 4138:2002, DSTU 4180:2003, DSTU 3768:2019.

This method allows you to assess the pathogenic load contained on the grain surface and the dynamics of its change under the influence of the studied technology. The method is intended for determining the contamination of grain with phytopathogenic fungi of the ascomycetes department: *Alternaria spp; Cladosporium spp., Fusarium spp, Helminthosporium spp, Septoria spp., Nigrospora spp.* Not applicable for: *Mucor spp; Penicillium sp; Aspergillus spp.* Three seed samples weighing 200 grains were transferred to a container with the addition of 20 cm^3 of sterile distilled water and mixed for 10 minutes by shaking. After shaking, 10 cm^3 of the liquid was transferred to two centrifuge tubes and centrifuged for 5 minutes at 600 rpm. After centrifugation, 9 cm^3 of the supernatant was drained, and the precipitate was resuspended in 1 cm^3 of liquid. Five slides of the Goryaev chamber were prepared from the suspension for each tube. The slides were analyzed using bright-field microscopy at a magnification of ×600. The characteristic formations were counted over the entire area of the Goryaev chamber. The number of formations per grain was calculated using the formula

$$C_{\text{H}} = C / \text{N}, \qquad (1)$$

where C_{H} – contamination of one grain;

N – number of grains in parallel (100 grains);

C – number of formations in 1 cm^3 of suspension. It is calculated by multiplying the number of formations determined over the entire area by the coefficient 1111.

Determination of seed contamination. This study consists in stimulating the growth and development of phytopathogenic microorganisms in grain using wet rolls of filter paper in controlled thermostat conditions. The method is implemented in accordance with DSTU 4138:2002.

This method allows you to assess the contamination of grain and the dynamics of its change under the influence of the technology under study. The method is intended for determining the contamination of grain with phytopathogenic fungi: *Alternaria spp; Cladosporium spp, Fusarium spp, Helminthosporium spp, Septoria spp., Mucor spp; Penicillium spp; Aspergillus spp., Nigrospora spp.* Three parallels, divided into four replications with a volume of 100 grains each, were placed on two-layer strips of moistened filter paper in one line at a distance of 1 cm from each other and 2–3 cm from the edges. The seeds placed on the paper were covered with a similar strip of paper and polyethylene film and rolled into rolls. The rolls were placed vertically in a container and incubated in a thermostat at 25 °C for 7 days. The results were calculated based on visual assessment of the characteristic manifestations of mold development and bright field microscopy. The quantitative result was calculated using the formula

$$C = \frac{K_1 + K_2 + K_3 + K_4}{K_0} \cdot 100\,, \qquad (2)$$

where C – contamination

K_1, K_3, K_3, K_4 – the number of infected grains in each of the four parallels;

K_0 – total number of grains in four parallels.

Method for determining the total number of molds and yeasts This study consists of surface inoculation of the DG-18 nutrient medium (Dichloranglycerol 18 agar, Merck) with subsequent incubation at 25°C and counting colonies. The method is implemented according to ISO 21527-2:2008. This method allows you to estimate the total number of viable molds and yeasts, including both pathogenic and non-pathogenic microbiota, and the dynamics of their change under the influence of the studied technology. Three parallels weighing 10 g were homogenized and formed subsequent dilutions 1:9 using PW buffer solution (Peptonewater, Merck). Then 0.1 cm^3 of each dilution was transferred to the center of the DG-18 nutrient medium agar plate. The liquid was distributed over the surface of the medium using a sterile microbiological spatula. After distribution, the inoculated nutrient medium was placed in a thermostat for incubation for 5 days at a temperature of 25 °C. The results were counted in transmitted light, separately taking into account the number of colonies characteristic of mold and yeast fungi. The number of colony-forming units (CFU) in one gram of grain was calculated using the formula

$$X = \frac{\sum C}{V \cdot (n_1 + 0.1n_2 + 0.01n_3) \cdot d}, \quad (3)$$

where X – result, CFU/g;

$\sum C$ – total number of colonies counted on all culture medium plates;

V – the volume of inoculum was 0.1 cm^3;

n_1, n_2, n_3 – the number of culture medium plates from the first to the last dilution on which 10 to 300 colonies grew;

d – the dilution factor that corresponds to the first dilution (with a higher sample concentration) that is taken into account (0.1 for a 10^{-1} dilution, 0.01 for a 10^{-2} dilution, etc.).

Statistical processing of results. Correlation. As an indicator of the direction of the relationship between the intensity of processing and the parameter to be analyzed, the Pearson correlation coefficient was used, which was calculated using the formulas

$$r_{x,y} = \frac{\sum(\bar{x} - x_i) \cdot (\bar{y} - y_i)}{\sqrt{\sum(\bar{x} - x_i)^2 \cdot \sum(\bar{y} - y_i)^2}} = \frac{Cov}{Sdx \cdot Sdy}, \quad (4)$$

where $r_{x,y}$ – correlation coefficient;

$\bar{x}$ – average result of the variable *x*;

x_i – individual result, variable *x*;

$\bar{y}$ – average result of the variable *y*;

y_i – individual result, variable *y*;

Sd – standard deviation of results.

The correlation coefficient was interpreted according to the following criteria:

− $r_{x,y}$=0 – lack of interconnection;

− $r_{x,y}$<0 – negative (inverse) relationship – when one quantity increases (decreases), the quantity associated with it decreases (increases);

− $r_{x,y}$>0 – positive (direct) relationship – when one quantity increases (decreases), the quantity associated with it increases (decreases);

The degree of correlation was assessed according to the following criteria:

− correlation coefficient value 0–0.3 – very weak correlation;

− correlation coefficient value 0.3–0.5 – weak correlation;

− correlation coefficient value 0.5–0.7 – medium correlation;

− correlation coefficient value 0.7–0.9 – high correlation;

− correlation coefficient value 0.9–1.0 – very high correlation.

Coefficient of determination. The coefficient of determination was used as an additional characteristic for assessing the relationship between the intensity of processing and the parameter under analysis. The calculation of the coefficient of determination was carried out according to the formula

$$R^2 = r_{x,y}^2, \quad (5)$$

where R^2 –coefficient of determination;

$r_{x,y}$– correlation coefficient.

The coefficient of determination was considered significant when the value of this indicator was higher than 0.7.

Regression analysis. Regression analysis was performed using the least squares method. Regression coefficients were calculated according to the formulas:

$$b_1 = \frac{Sd_y}{Sd_x} r_{xy}; \qquad b_0 = \bar{y} - b_1\bar{x},$$

where b_1 – slope (rate of change of *y* depending on *x*);

b_0 – intercept (segment on the *y*-axis at *x*=0);

Sd_y – standard deviation of the variable *y*;

Sd_x – standard deviation of the variable *x*;

r_{xy} – correlation coefficient;

$\bar{y}$ – the average value of the variable *y*;

$\bar{x}$ – the average value of the variable *x*.

The interpretation of the relationship was carried out with the help of a comprehensive approach using regression analysis.

Results of the research and their discussion

Determination of contamination. According to the results of a microbiological study of the surface contamination of the studied grain, which included a negative control and four experimental variants, spores of such pathogenic fungi as *Alternaria spp., Cladosporium spp., Fusarium spp., Helminthosporium spp.,* and *Nigrospora spp.* were detected. The range of values for quantitative assessment of contamination of wheat grain samples in three parallels and their percentage dynamics relative to the initial value (control) depending on the frequency of EMF are given in Table 1. Fig. 1 shows a visual ratio of the average values of contamination of wheat grain by the studied microbiota.

Table 1 – Results of wheat grain contamination before and after EMF treatment of different frequencies

Pathogenic fungi	Grain contamination ranges in three parallel experiments depending on EMF treatment of different frequencies, spores/grain					Average percentage contamination of grain relative to control depending on EMF treatment of different frequencies, %				
	Control	EMF frequencies, Hz				Control	EMF frequencies, Hz			
		10	16	24	30		10	16	24	30
Cladosporium spp.	58–47	22–14	28–11	6–3	3–0	100.00	36.84	36.84	7.02	1.75
Alternaria spp.	78–69	22–14	28–11	8–3	6–3	100.00	9.09	10.39	7.79	5.19
Helminthosporium spp.	17–3	3–0	3–0	3–0	3–0	100.00	19.84	9.92	9.92	9.92
Fusarium spp.	422–389	56–20	33–25	28–9	19–11	100.00	9.03	7.37	4.43	3.92
Nigrospora spp.	17–14	8–3	6–3	6–0	3–0	100.00	31.25	25.00	18.8	12.50

Fig. 1. shows a visual correlation between the average values of wheat grain contamination with the studied microbiota before (control) and after treatment with EMF of different frequencies.

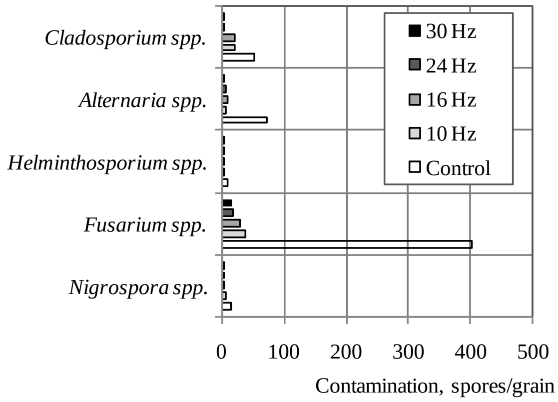


Fig. 1 - Dependence of average values of contamination of wheat grain on EMF

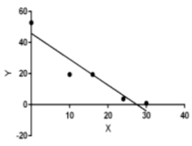
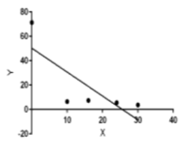
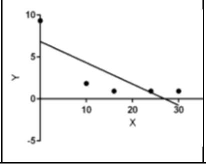
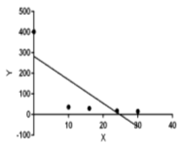
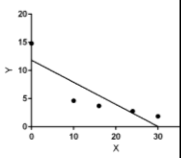
The results presented demonstrate the high efficiency of the studied technology in relation to contamination by microorganisms such as *Cladosporium spp.* and *Fusarium spp.* The most effective level of treatment for these pathogenic fungi was found to be EMF treated with a frequency of 30 Hz for 6 min. It allowed to achieve a decrease in the average values of wheat grain contamination from 52.77 to 0.93 spores/grain for *Cladosporium spp.* and from 401.81 to 15.74 spores/grain for *Fusarium spp.* This reduces the seeding of grain with these pathogenic fungi by 57.00 and 25.53 times, respectively, compared to grain not treated with EMF (control).

The lowest efficiency of reducing contamination from wheat processing was shown by *Nigrospora spp.*, for which it was possible to reduce the output value to 12.50% (or 8.00 times) of the initial value.

However, it should be noted that the difference between the initial concentrations of the studied microorganisms makes it difficult to generalize the conclusion about the effectiveness. In addition, the contamination study is significantly affected by the homogenization of the sample and the physical factors affecting the grain subjected to EMF treatment. Factors such as vibration, aeration and shaking can introduce additional non-uniformity into the distribution of this parameter.

The results of the study of the relationship between EMF grain treatment and a decrease in the studied indicator are shown in Table 2. Correlation analysis demonstrates a significant relationship between an increase in the intensity of treatment and a decrease in the contamination index in relation to microorganisms such as *Cladosporium spp.* and *Nigrospora spp.*, for which a linear dependence and an inverse correlation are observed

Table 2 – Statistical analysis of the relationship between the intensity of EMF treatment and infection

Statistics	*Cladospo-rium spp.*	*Alternaria spp.*	*Helmintho-sporium spp.*	*Fusarium spp.*	*Nigrospora spp.*
Correlation coefficient	–0.9478	–0.7861	–0.8104	–0.792	–0.8735
Coefficient of determination	0.8981	0.6180	0.6564	0.6277	0.7631
Linear Regression Equation	y=45.87–1.664x	y=50.29–1.962x	y=6.850–0.2535x	y=282.4–11.38x	y=11.83–0.3924x
Linear dependence graph					

The absence of a significant relationship in other cases indicates the absence of a linear relationship between the intensity of treatment and the contamination index. This is explained by the lack of significant effectiveness of increasing the intensity of treatment. To analyze the effectiveness, an assessment of the dispersion of the relative results obtained at different frequency intervals of EMF treatment was carried out. The results are presented in Table 3.

Table 3 – Estimation of the variations of relative results obtained at different intervals of EMF treatment intensity, %

Pathogenic fungi	EMF frequency intervals, Hz		
	10–30	16–30	24–30
Cladosporium spp.	35.09	35.09	5.27
Alternaria spp.	5.20	5.20	2.60
Helminthosporium spp.	9.92	0.00	0.00
Fusarium spp.	5.11	3.45	0.51
Nigrospora spp.	18.75	12.50	6.30

According to the results obtained, there was no significant increase in the effectiveness of the treatment effect for the indicator of contamination with microorganisms such as *Alternaria spp., Helminthosporium spp.* and *Fusarium spp.*

For pathogenic fungi such as *Alternaria spp.* and *Fusarium spp.,* the optimal level of treatment was an EMF frequency of 16 Hz, and for *Helminthosporium spp.* 10–16 Hz. The subsequent increase in intensity within the studied values did not demonstrate a significant effect.

However, given the insignificant level of determination coefficients found for *Alternaria spp., Helminthosporium spp.,* and *Fusarium spp.,* one should take into account the lack of evidence of the relationship between the reduction in contamination and treatment as such. It is possible that this indicator was influenced by extraneous factors. Additional studies are required, at least at the same level of contamination with different microorganisms.

Determination of infection. According to the results of the microbiological study of the contamination of the studied grain, which included a negative control and four experimental variants, spores of such pathogenic fungi as *Alternaria spp., Cladosporium spp., Fusarium spp., Helminthosporium spp.,* and *Nigrospora spp.* were detected. The results of the quantitative assessment of contamination in three parallels and the percentage dynamics of changes in the average values of contamination relative to the output value depending on the frequency of EMF are given in Table. 4. Fig. 2 shows the dynamics of the ratio of the average values of contamination of wheat grain.

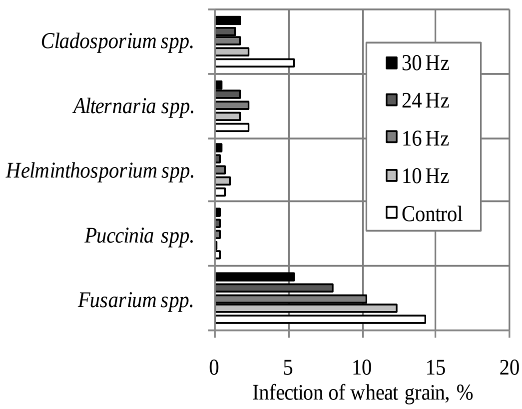


Fig. 2. Dynamics of average values of wheat grain contamination

As the results show, a stable decrease in the infection rate is observed in relation to such microorganisms as *Cladosporium spp.* and *Fusarium spp.* For these pathogenic fungi, the following infection rate reduction was achieved with the use of EMF treatment relative to the control – up to 25.00% at an EMF frequency of 24 Hz for *Cladosporium spp.* and up to 37.21% at an EMF frequency of 30 Hz for *Fusarium spp.*

In all other cases, the effect of the treatment gave unstable results that are difficult to interpret as effectiveness or ineffectiveness. One of the probable reasons is the low initial level of infection by such pathogenic fungi as *Alternaria spp., Helminthosporium spp.* and *Puccinia spp.* However, a possible conclusion may be the existence of a minimum achievable level of infection reduction that can be achieved using this type of treatment. Potentially, this (achievable) level may be in the range of 3–0.5%.

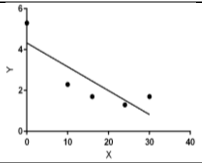
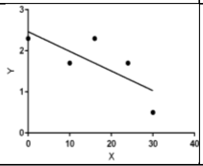
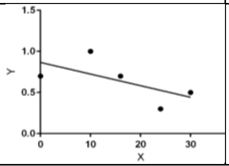
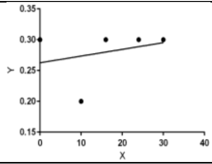
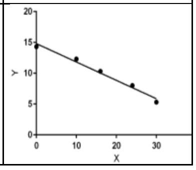
The results of the study of the relationship between treatment and the decrease in the studied indicator are shown in Table 5.

Table 4 – Results of wheat grain contamination before and after treatment with EMF of different frequencies

Pathogenic fungi	Grain contamination ranges in three parallel experiments depending on EMF treatment of different frequencies, %					Dynamics of wheat grain contamination relative to the control depending on the frequency of EMF, %				
	Control	EMF frequencies, Hz				Control	EMF frequencies, Hz			
		10	16	24	30		10	16	24	30
Cladosporium spp.	7–4	4–1	2–1	2–1	3–1	100.00	43.75	31.25	25.00	31.25
Alternaria spp.	3–2	2–1	3–2	3–1	1–0	100.00	71.43	100.00	71.43	21.43
Helminthosporium spp.	1–0.5	1	1–0.5	0.5–0	0.5–0	100.00	150.00*	100.00	50.00	75.00
Puccinia spp.	0.5–0	0.5–0	0.5–0	0.5–0	0.5–0	100.00	50.00	100.00	100.00	100.00
Fusarium spp.	17–12	14–10	11–10	10–5	7–4	100.00	86.05	72.09	55.81	37.21

* *statistical outlier associated with a low initial value that fits within the measurement uncertainty.*

Table 5 – Statistical analysis of the relationship between treatment intensity and infection

Statistics	*Cladosporium spp.*	*Alternaria spp.*	*Helminthosporium spp.*	*Puccinia spp.*	*Fusarium spp.*
Correlation coefficient	–0.8462	–0.7671	–0.6026	0.2855	–0.9903
Coefficient of determination	0.7093	0.5845	0.4052	0.08152	0.9802
Linear Regression Equation	y=4.327–0.1167x	y=2.465–0.04783x	y=0.8661–0.01413x	y=0.2626+0.001087x	y=14.81–0.2978x
Linear dependence graph					

According to the results obtained, a significant relationship and inverse correlation between the level of infection and the intensity of treatment were found for such microorganisms as *Cladosporium spp.* and Fusarium spp. For these pests, increasing the intensity of treatment up to 30 Hz demonstrated an effective linear reduction in infection.

For these pathogenic fungi, EMF grain treatment with a frequency of 24 Hz demonstrated the possibility of effective reducing the infection of *Cladosporium spp.* relative to the control (untreated grain) by 25.00% (up to 1.33%). EMF grain treatment with a frequency of 30 Hz allowed to reduce the infection of *Fusarium spp.* relative to the control by 37.21% (up to 5.33%)

Determination of the total number of molds and yeasts. The ranges of the total number of yeasts and molds in wheat grain in three parallel experiments depending on the treatment with EMF of different frequencies are shown in Table 6, and the dynamics is shown in Fig. 3.

According to the analysis, the highest efficiency in terms of mold concentration was achieved by the treatment with parameters 30 Hz, which allowed to reduce the total mold load by 96.84% from the output value. The highest efficiency in terms of yeast concentration was demonstrated by the treatment with parameters 16 Hz, which allowed to reduce the total yeast load by 95.76% from the output value.

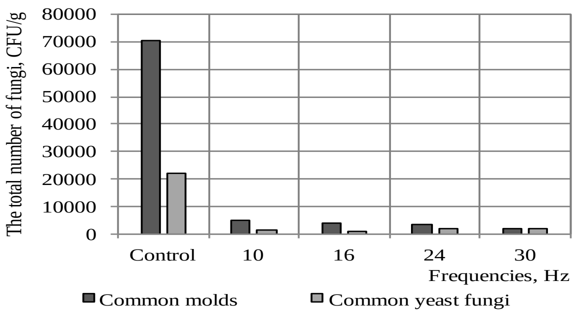


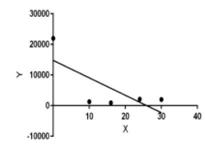
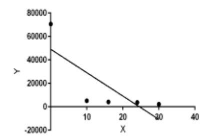
Fig. 3. Indicators of average values of the number of mold and yeast fungi

Table 6 – Ranges of total number of yeast and mold fungi in wheat grain in three parallel experiments depending on EMF treatment of different frequencies, (CFU/g·10^3)

Number of fungi	Control	EMF frequencies, Hz			
		10	16	24	30
Mold	75–68	5.4–4.9	4.4–3.7	4.1–3.3	2.4–2.1
Yeast	24–21	1.5–1.0	1.1–0.8	2.5–1.9	2.2–1.8

The statistical processing of the relationship between the dynamics of microorganisms and intensive treatment is demonstrated in table 7.

Table 7 – Statistical analysis of the relationship between the concentration of yeast and mold fungi and the intensity of EMF treatment

Statistics	Common mold fungi	Common yeast fungi
Correlation coefficient	–0,7316	–0,7828
Determination coefficient	0,5352	0,6128
Linear Regression Equation	y = 14778–569,4x	y = 49080–1994x
Linear dependence graph		

In both cases the inverse correlation between the concentration of microorganisms and treatment intensity was revealed. It demonstrates actual relationship though it doesn't substantiate it's cause-and-effect nature. However, the determination coefficient in both cases didn't reach the significant level and it can be connected with instability of the indicators within 10^3 degree.Taking into account quantitative indicators of concentration, the general conclusion testifies to the ability of EMF treatment to significantly reduce mycology load on grain. However, the investigated parameters of the treatment don't cause complete destruction of viable microorganisms.

Conclusion

1. It was established that it is possible to reduce the contamination of wheat grain with phytopathogenic microorganisms *Cladosporium spp., Alternaria spp., Helminthosporium spp.*, *Fusarium spp.* and *Nigrospora spp.* by treating the grain infected with them with EMF in the frequency range of 10–30 Hz. The highest effect is achieved at an EMF frequency of 30 Hz.

2. It was shown that the treatment of wheat grain with EMF with a frequency of 30 Hz allowed to significantly reduce the contamination of *Cladosporium spp.* and *Fusarium spp.* – respectively, to 1.75% and 3.92% of the initial indicator. The contamination of microorganisms *Alternaria* and *Helminthosporium* after grain treatment at a frequency of 30 Hz was slightly higher and amounted to 5.15% and 9.97% of the output indicator, respectively. In relation to *Nigrospora*, the disinfection efficiency after wheat grain treatment was the lowest– the output value of contamination decreased to 12.50% of the initial value.

3. Based on the results of studies of the dynamics of disinfection of pathogenic microorganisms, a stable decrease in the infection rate was established in relation to *Cladosporium spp.* and *Fusarium spp.* For these microorganisms, the level of reduction that was achieved after EMF treatment with a frequency of 30 Hz reached 31.25% and 37.21% relative to the output value, respectively. In all other cases, the effect of EMF treatment gave unstable results, one of the probable reasons was the low initial level of infection by pathogens such as *Alternaria spp.*, *Helminthosporium spp.* and *Puccinia spp.* However, an important conclusion may be the existence of a minimum achievable level of infection reduction that can be achieved using EMF treatment of wheat grain with frequencies of 10–30 Hz. Potentially, this level of infection may be in the range of 3.0–0.5%.

4. It was found that the highest reduction in the concentration of mold fungi was provided by the treatment of wheat grain with EMF at a frequency of 30 Hz, which allowed to reduce the total mold load by 96.84% of the output value. The greatest efficiency in reducing the concentration of yeast fungi was shown by the treatment of grain with EMF at a frequency of 16 Hz, which allowed to reduce the total yeast load by 95.76% of the output value.

5. Correlation analysis of the relationship between treatment intensity and infection showed a significant relationship and an inverse correlation between the level of infection and treatment intensity and was found for microorganisms such as *Cladosporium spp.* and *Fusarium spp.* For these pests, increasing the treatment intensity to 30 Hz showed an effective reduction in infection.

6. A high inverse correlation was found between the concentration of microorganisms and the intensity of treatment, which demonstrates the existing relationship, but does not substantiate its cause-and-effect nature. However, the coefficients of determination for mold and yeast fungi (0.535 and 0.613, respectively) did not reach a significant level, which can be attributed to the instability of the indicators within the 10^3 degree range.

7. Considering the quantitative indicators of the concentration of microorganisms, the general conclusion indicates the ability of EMF treatment to significantly reduce the mycological load on wheat grain. However, the studied EMF grain treatment regimes do not cause the complete destruction of viable microorganisms and require further more extensive study.

References:

1. Kirpa MYa. Scientific substantiation of innovative industrial grain storage technologies. Bulletin of the Inst of Agriculture of the steppe zone NAAS of Ukraine. 2013;5:93-98 (in Ukrainian).
2. Havrylenko OS, Khomitska OA, Zagorulko OV. Assessment of the influence of microbiological processes during the storage of spring wheat grain. Bulletinof the Poltava State Agrarian Academy. 2016;4:31-35 (in Ukrainian).
3. Zhelobkova M, Stankevych G. Practical questions for silo bags grain storage technology. J Grain Products and Mixed Fodder's. [Internet]. 2019 [cited 2025 Apr 23];19(2):10-16. Available from: https://doi.org/10.15673/gpmf.v19i2.1442
4. Kyurchev SV. The cooling process in granaries during the storage of grain products with further implementation in production. J Engineeringofnature management. [Internet]. 2019; [cited 2025 Apr 23]; 1(11):38-46. Available from: https://repo.btu.kharkov.ua/bitstream/123456789/1765/1/7.pdf(in Ukrainian).
5. Shejbal J. Preservation of cereal grains in nitrogen atmospheres. J Resource Recovery and Conservation. [Internet]. 1979[cited 2025 Apr 23];4(1):13-29.Available from: https://doi.org/10.1016/0304-3967(79)90034-9
6. Stankevych GM, Babkov AV. Ozone in wheat grain processing and storage technologies. Kherson: Gryn D.S.; 2015. (in Ukrainian).
7. Chorna MO. Application of electromagnetic radiation for drying and disinfection of cereal seeds. Bulletin of the Petro Vasylenko Kharkiv National Technical University ofAgriculture. 2017; 186:146-147. (in Ukrainian).
8. Dalmoroa A, Barba A, Caputo S, Marra F, Lamberti G. Microwave technology applied in post-harvest treatments of cereals and legumes. J Chemical engineering transaction [Internet]. 2015[cited 2025 Apr 23];44:13-8. Available from: https://doi.org/10.3303/CET1544003.

9. Marinković B, Grujić M, Marinković D, CrnobaracJ, Marinković J, Jaćimović G, et al. Use of biophysical methods to improve yields and quality of agricultural products. J Agricultural Sciences [Internet]. 2008[cited 2025 Apr 23];53(3):235-242. Available from:https://doi.org/10.2298/JAS0803235M
10. Pittman UL. Effect of magnetics seed treatment on yields of barley, wheat, and oats in southern Alberta. Canadian J of Plant Science [Internet]. 1977 Jan[cited 2025 Apr 23];57(1):37-45. Available from: https://doi.org/10.4141/cjps77-006
11. Sarraf M, Kataria S, Taimourya H, Oliveira L, Renata S, Menegatti D, et al. Magnetic Field (MF) Applications in Plants: An Overview. J Plants [Internet]. 2020[cited 2025 Apr 23];9(9):1139. Available from: https://doi.org/10.3390/plants9091139.
12. Alikamanoglu S, Sen A. Stimulation of growth and some biochemical parameters by magnetic field in wheat (Triticum aestivum L.) tissue cultures. African J of Biotechnology [Internet]. 2011[cited 2025 Apr 23];10(53):10957-10963. Available from: https://doi.org/10.5897/AJB11.1479
13. Rochalska M, Orzeszko-Rywka A. Magnetic field treatment improves seed performance. J Seed Sci. &Technol.[Internet]. 2005 Oct [cited 2025 Apr 23];33(3):669-674. Available from: https://doi.org/10.15258/sst.2005.33.3.14
14. Pietruszewski S, Muszyński S, Dziwulska A. Electromagnetic fields and electromagnetic radiation as non-invasive external stimulants for seeds (selected methods and responses). J Int. Agrophys. [Internet]. 2007 [cited 2025 Apr 23]; 21(1): 95-100. Available from: https://www.researchgate.net/publication/26552199
15. Inozemcev GB. Electromagnetic energy as a factor of activation of development and increase of productivity in crop production. Scientific Bulletin of NULES of Ukraine. [Internet]. 2012 [cited 2025 Apr 23];174(1):7-10.Available from: http://nbuv.gov.ua/UJRN/nvnau_tech_2012_174%281%29__3 (in Ukrainian).
16. Olkhovskyi VO, Dudarev IM. Methods of separation and grain mass separators. J Agricultural machines. [Internet]. 2021 [cited 2025 Apr 23];47:102-112. Available from: https://doi.org/10.36910/acm.vi47.655
17. Boshkova I. Assessment of efficiency of drying grain materials using microwave heating / I. Boshkova, N. Volgusheva, A. Titlov, S. Titar, L. Boshkov //Eastern-European J of Enterprise Technologies[Internet]. 2019. [cited 2025 Apr 23];1(8): 78-85. Available from: http://nbuv.gov.ua/UJRN/Vejpte_2019_1(8)__10
18. Osokina N, Liubych V, Novikov V, Leshchenko I, Petrenko V, Khomenko S, Zorunko V, Balabak O, Moskalets V, Moskalets T. Effect of electromagnetic irradiation of emmer wheat grain on the yield of flattened wholegrain cereal Eastern-European J of Enterprise Technologies [Internet]. 2020 [cited 2025 Apr 23]; 6(11 (108):17- 26. Available from: https://doi.org/10.15587/1729-4061.2020.217018
19. Ijaz B, Jatoi SA, Ahmad D, Masood MS, Siddiqui SU. Changes in germination behavior of wheat seeds exposed to magnetic field and magnetically structured water. Afr. J. Biotechnol. [Internet]. 2012 [cited 2025 Apr 23]; 11(15): 3575–85. Available from: http://doi:10.5897/ajb11.2927
20. Kovalenko OI, Kivva FV, Kalinichenko SV, Kovorotny OL. Peculiarities of the direct and indirect influence of low-power electromagnetic fields on plant seeds and microorganisms. J Radio physics and electronics. [Internet]. 2007[cited 2025 Apr 23];12(1): 273-282. Available from: http://dspace.nbuv.gov.ua/handle/123456789/10772 (in Russian).
21. Schmidt M., Zannini E, Arendt EK. Recent Advances in Physical Post-Harvest Treatments for Shelf-Life Extension of Cereal Crops. J Foods [Internet]. 2018 [cited 2025 Apr 23];*7*(45):[about 22pp.]. Available from: https://doi.org/10.3390/foods7040045
22. Zein DM, Hussein A. Ability of magnetic field to protect wheat crops during storage. J of Plant Protection Research [Internet]. 2019 [cited 2025 Apr 23];59(2):281-286.Available from:https://doi.org/10.24425/jppr.2019.129740
23. Ueno S, Shigemitsu T. Bioelectromagnetism: History, Foundations and Applications. Boca Raton: CRC Press; [Internet].2022 [cited 2025 Apr 23]; Available from: https://doi.org/10.1201/9781003181354
24. Kovra Yu, Stankevich G, Yehorova A. Influence of the extremely low-frequency electromagnetic treatment on microbiological indicators of wheat grain. J Scientific Works of NUFT [Internet]. 2021[cited 2025 Apr 23];27(2): 162-169.Available from: https://doi.org/10.24263/2225-2924-2021-27-2-18 (in Ukrainian).
25. Stankevych G, Kovra Y, Borta A. Formation of the quality of wheat grain by extremely low frequency electromagnetic field treatment. J Technology Audit and Production Reserves [Internet]. 2022[cited 2025 Apr 23]; 4(3(66)): 38–44. Available from: http://doi.org/10.15587/2706- 5448.2022.263484
26. Inhan-Garip A, Aksu B, Akan Z, Akakin D, Ozaydin AN, San T. Effect of extremely low frequency electromagnetic fields on growth rate and morphology of bacteria.Int J of Radiation Biol. [Internet]. 2011[cited 2025 Apr 23]; 87(12):1155–1161. Available from: https://doi.org/10.3109/09553002.2011.560992
27. Oncul S, Cuce EM, Aksu B, Inhan Garip A. Effect of extremely low frequency electromagnetic fields on bacterial membrane. Int Jof Radiation Biol. [Internet]. 2015[cited 2025 Apr 23];92(1):42–49.Available from: https://doi.org/10.3109/09553002.2015.1101500
28. Jabłońska J, Dubrowska K, Gliźniewicz M, Paszkiewicz O, Augustyniak A, Grygorcewicz B, Konopacki M, Markowska-Szczupak A, Kordas M, Dołęgowska B, Rakoczy R. The use of the electromagnetic field in microbial process bioengineering. J Adv Appl Microbiol. [Internet]. 2022[cited 2025 Apr 23];121:27-72. Available from: https://doi.org/10.1016/bs.aambs.2022.08.002

ВПЛИВ ОБРОБКИ ЗЕРНА ПШЕНИЦІ ЕЛЕКТРОМАГНІТНИМ ПОЛЕМ ВКРАЙ НИЗЬКИХ ЧАСТОТ НА ЇЇ МІКРОБІОТУ

Ю.В. Ковра[1], хімік лабораторії харчової безпеки, *E-mail*: yuriykovra@gmail.com
Б.С. Жуков[1], заступник керівника молекулярно-генетичної та мікробіологічної лабораторії, *Email*: brs.alchemist@gmail.com
Г.М. Станкевич[2]**,** доктор технічних наук, професор, *Email*: georgii.stn@gmail.com
[1]Випробувальний Центр ІП «СЖС Україна»
вул. Чорноморського козацтва, 103,
м. Одеса, Україна, 65003
[2]Кафедра технології зерна і комбікормів
Одеський національний технологічний університет
вул. Канатна, 112, м. Одеса, Україна, 65039

Анотація. Метою дослідження була обробка контамінованих зразків зерна пшениці електромагнітним полем (ЕМП) вкрай низьких частот ВНЧ на зниження її мікробіологічного обсіменіння, що сприятиме підвищенню якості зерна та термінів його зберігання. Після обробки визначали загальну кількість пліснявих та дріжджових грибів у оброблених та контрольних зразках зерна, аналізували динаміку зараженості відносно вихідного значення та обраного діапазону частот ЕМП, проводили статистичний аналіз взаємозв'язку інтенсивності обробки зразків зерна та їх зараженості. При дослідженні встановлено можливість зниження контамінованості зерна пшениці фітопатогенними мікроорганізмами *Cladosporium, Alternaria, Helminthosporium, Fusarium* та *Nigrospora* за допомогою обробки зараженого ними зерна ЕМП у діапазоні частот 10–30 Гц. Найбільш високий ефект досягається за частоти ЕМП 30 Гц. Показано, що обробка зерна пшениці ЕМП з частотою 30 Гц дозволила суттєво знизити контамінованість *Cladosporium* та *Fusarium* — відповідно до 1,75 % та 3,92 % від вихідного показника. Контамінованість мікроорганізмами *Alternaria* та *Helminthosporium* після обробки зерна за частоти 30 Гц була дещо вищою та склала відповідно 5,15 % і 9,97 % від вихідного показнику. У відношенні *Nigrospora* ефективність знезараження після обробки зерна пшениці була найбільш низькою — вихідне значення контамінованості знизилось до рівня 12,50 % від початкового значення. Встановлено, що найбільш високе зниження концентрації пліснявих грибів забезпечила обробка зерна пшениці ЕМП з частотою 30 Гц, яка дозволила знити загальне плісняве навантаження на 96,84 % від вихідного значення. Найбільшу ефективність з боку зниження концентрації дріжджових грибів показала обробка зерна ЕМП з частотою 16 Гц, яка дозволила знизити загальне дріжджове навантаження на 95,76 % від вихідного значення. Враховуючи кількісні показники концентрації мікроорганізмів, загальний висновок свідчить про здатність електромагнітної обробки суттєво знижувати мікологічне навантаження на зерно пшениці. Однак досліджені режими обробки зерна електромагнітним полемне спричиняють повного знищення життєздатних мікроорганізмів і потребують у подальшому більш розширеного вивчення.

Ключові слова:зерно пшениці, вкрай низькочастотне електромагнітне поле, обробка електромагнітним полем, мікробіологічні показники, зберігання, кореляційний та регресійний аналіз