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Peculiarities of wheat seed resonant exposure to microwave radiation through oxygen-enriched water

Subject and Purpose. *Peculiarities are considered of a purposeful modification of the functional indices of wheat seeds upon their soaking in water preliminarily enriched with oxygen and simultaneously irradiated with a low-intensity electromagnetic field (EMF). The aim is to investigate effectiveness of such an indirect exposure of wheat seeds to a low-intensity electromagnetic field related to discrete bands in the extremely high-frequency (EHF) range and depending on the initial state of seeds, "norm" or "pathology".*

Methods and Methodology. *The study comprises experimentally approved radio-physical, radio-engineering and chemical methods. Generators G4-141 (37.5…53.57 GHz) and G4-142 (53.57…78.33 GHz) serve as radiation sources. Oxygen is obtained by reacting a hydrogen peroxide solution with potassium permanganate. The oxygen enrichment of water is executed during its irradiation. The verification of indirect electromagnetic field exposure is based on changes demonstrated by such functional indices of seeds as germination energy and mean lengths of roots and seedlings in each sample.*

Results. *A possibility has been established to modify the functional indices of wheat seeds through their soaking in water preliminarily irradiated with an EMF and simultaneously enriched with oxygen. It has been revealed that the efficiency of the effect depends on whether the seeds are in "normal" or "pathological" state and that a feasibility exists of recovering properties lost in a "pathology" state. The role that the oxygen in the water imbibing the seeds plays in the germination process has been demonstrated. Peculiarities as to the efficiency of wheat seed EMF exposure through the oxygen-enriched water have been shown depending on the signal frequency and length of exposure and on the total energy load.*

Conclusion. *It has been found that substances, including living entities, can be electromagnetically exposed through water. The water-dissipative model of substance exposure to the electromagnetic field has been validated. In this model, water is one of the targets liable to changing its properties at the EMF exposure. This point has been indirectly confirmed by the studies of the states of seeds upon their soaking in the pre-irradiated water. The gas model of the EMF interaction with a substance has been verified, too. A possibility of oxygen activation at resonance irradiation has been shown. Fig.: 4. Tab. 2. Ref.: 19 items.*

Key words: *electromagnetic field, wheat seeds, water, indirect irradiation, oxygen, gas resonances.*

Development and introduction of electromagnetic technologies open up promising opportunities for targeted regulation of biological objects in medicine, pharmacology, agriculture, and ecology [1, 2]. Of great interest are mechanisms of substance exposure to the electromagnetic field (EMF). With all the organization complexity of living entities, different biological links and structures can be EMF influenced, giving rise to innumerable interdependent reactions and processes discussed in the literature [3—6].

Significant biological effects have been found at the low-intensity EMF exposure characterized by that the increased general temperature of the irradiated object does not exceed natural thermal background fluctuations of $t \le 0.1\,°C$ temperature (the power flux density is under 10 mW/cm^2) [7]. The frequency-dependent exposure to electromagnetic fields within narrow bands is noted in [8—10]. Resonance effects in gas and water media are normal for various substances and biological tissues, being the most pronounced in complex bio-objects where the role of large macromolecules, direct and feedback systems and indirect neurogumoral regulation is significant [11]. Non-resonance effects of EMF absorption by water media and tissues are associated with the emergence of convective movements, molecular diffusion, structural rearrangement of molecules and can influence membrane processes and metabolism of the cells [12, 13].

One of the relevant models today is the water-dissipative model where water is thought of as a main target of the EMF exposure, taking into consideration the structure and properties of water in view of its hydrogen bonds, clusters, dipoles, etc.

Another important factor is water-dissolved gases whose activation as a result of the EMF exposure is the concern of the gas model. In the mm wave range, effects arise caused by resonant polarization of certain gases, their oxides and compounds (O_2, O_3, N_2, NO, NO_2, etc.), see [8–10]. The spectra of resonant transparency of thin water layers and absorption spectra of bio-objects are found in the UHF range. Thus, the 150.176…150.644 GHz frequency band corresponds to the resonant absorption of nitrogen oxide (NO). The NO molecule is a neurotransmitter, a powerful homeostasis factor, a platelet aggregation inhibitor, etc. penetrating directly into the cell. It also triggers biochemical reactions. It has radiation and absorption molecular spectra meeting spectra of the relict microwave background radiation and water transparency. It is supposed that the UHF radiation within 150.176…150.644 GHz is a leading factor in the living cell evolution [8].

The EMF resonant absorption is found in the 40.0, 42.2 GHz, 50.3, and 58.0 GHz bands related to the excitation of ozone and hydrogen atoms, respectively [11, 14].

Special attention is given to the oxygen model considering oxygen as one of the main dissolved gases that determine existence of living entities. The oxygen absorption holds within the 61.0 and 64.5 GHz bands in the millimeter wave range. The result of the low-intensity EHF exposure is the accelerated delivery of oxygen and other substances to cells and tissues due to their transport through liquid media. It is assumed that the changes in the membrane transport function are associated with the presence of self-accelerating mechanisms developing in their lipid phase, a possible cause of the affected metabolism of the irradiated cells, including the appearance of stimulating effects. Oxygen exerts effects on the formation and accumulation of radical and peroxide states and on the development of autocatalytic processes, such as chain reactions in the lipid phase of membranes with the accumulation of final products, which causes changes in their functional state. Without oxygen, the conformational shifts in the protein phase of membranes are blocked, as well as the oxidation of sulfhydryl and other groups, which may affect changes in the membrane permeability in the presence of oxygen. The effect of oxygen that in the resonance band of the EHF range can transmit some part of the absorbed energy to hydrogen-bound water molecules and trigger the chains of excitation, forming a general frequency dependence of the biological effect, is considered in [15]. On the EMF exposure, the free radical reactions in the membranes of cell components increase, which also contributes to changes in their permeability.

An important point in this model of bio-object-to-EMF exposure is forming hydrogen peroxide (H_2O_2) in the aqueous superoxide solutions by superoxide dismutase, which relates to both reactive and active oxygen forms. The concentration values of the formed hydrogen peroxide and other peroxide states determine the development of biological effects — from the photosynthesis stimulation to the cell damage. In the presence of so formed peroxides, the photosynthesis processes are intensified together with the accumulation of pigments. It is known that photosynthetic oxygen is formed from hydrogen peroxide of exogenous and endogenous origin rather than from water. Therefore, an increase in peroxides in the cell by any reason corresponds to the photosynthesis intensification (the hydrogen peroxide model) [15].

Attempts are known to link EMF exposure effects to biochemical changes in the structural elements of biological cells. It is assumed that there are several sensory systems that are characterized by their own resonant frequencies and are liable to be influenced by the UHF electromagnetic field [16].

The aim of the work is to investigate effectiveness of the wheat seed exposure to a low-intensity EMF through oxygen-enriched water in discrete bands of the UHF range depending on the initial state of the seeds, "normal" or "pathological".

1. Measurement technique and equipment. Generators G4-141 (37.5…53.57 GHz) and G4-142 (53.57…78.33 GHz) are taken as radiation sources for signals of power $P \leq 5$ mW in discrete UHF bands. The generator waveguide outputs are loaded with horn antennas having a square aperture of roughly 40 cm^2. The power stream density (PSD) is ≈0.1 mW/cm^2 and the radiation unevenness does not exceed 3 dB.

The research objects are soft-grade wheat seeds of 2015 harvest with different initial indices.

The oxygen is produced on lab-quality equipment from the reaction of hydrogen peroxide solution with potassium permanganate [17]. The reaction starts as

$$3H_2O_2 + 2KMnO_4 \rightarrow 2KOH + 2MnO_2 + \\ + 2H_2O + 3O_2. \qquad (1)$$

The appearance of the manganese dioxide is accompanied by the following competing process

$$2H_2O_2 - (MnO_2) \rightarrow 2H_2O + O_2. \qquad (2)$$

To have water enriched with oxygen, we use a self-designed device. In it, a container homing the chemical reactions is combined with a system of tubes for the delivery and uniform oxygen distribution throughout the water.

The oxygen enrichment process takes 15 minutes. Then dry seeds are soaked in the water until the so-called "oxygen control" state comes.

The indirect seed exposure to the EMF is by soaking of dry seeds in pre-irradiated water. The irradiation of water is carried out simultaneously with its oxygen enrichment.

The discrete UHF bands chosen for the EMF exposure are: 61.0 GHz band of oxygen absorption and 58.0 and 42.2 GHz frequency bands off the resonance. The exposures were 5, 10, 30, and 60-minute long. The seeds were soaked in the water for 4 hours at a temperature of 23 ± 1 °C. With water drained, the seeds were spread out in Petri dishes, 50 samples per dish, for the following aeration in a thermostat. The 72-hour germination agrees with certification system GOST 10968-88 [18].

Here, the thermal treatment of seeds means their 60-minute exposure to a constant temperature of 75 ± 0.5 °C in a water ultra-thermostat (U-10).

The effectiveness of the indirect water-mediated exposure to EMF was evaluated from changes in the seed functional indices: 1) germination energy (E_g, %), 2) mean root length ($L_{r\ mid}$, mm), and 3) seedling mean length ($L_{s\ mid}$, mm) in each set with respect to their standard deviations.

The results were processed using the Student's test in terms of statistical analysis program "BioStat 2008".

2. Discussion of the exposure results. First we consider wheat seeds characterized by initially

Table 1. **Comparison of functional indices of "normal"-state wheat seeds after their indirect exposure to a low-intensity EMF through the oxygen-enriched and pre-irradiated water** (* $-p < 0.05$; ** $-p < 0.001$)

Exposure mode			Functional indices					
O_2	EMF		E_g, %		$L_{r\ mid}$, mm		$L_{s\ mid}$, mm	
T, min	f, GHz	T, min	E_g	RMS	$L_{r\ mid}$	RMS	$L_{s\ mid}$	RMS
Control			90.0	4.7	19.9	5.3	15.6	2.7
15	Oxygen control		92.1	2.0	24.0*	2.4	16.3	1.8
	61.0	5	90.4	2.6	28.4*	2.7	18.2*	1.4
		10	94.0	2.5	31.9**	1.6	19.3**	0.8
		30	93.3	2.4	21.7	2.5	15.8	1.4
		60	92.8	4.2	24.9	2.3	18.0	1.8
	58.0	5	91.3	1.6	26.5	5.0	16.8	2.9
		10	91.7	3.7	25.1	2.7	16.0	1.4
		30	91.7	2.9	24.0	1.6	16.6	0.7
		60	91.0	3.0	20.7*	3.2	15.0	2.5
Control			91.4	2.3	18.4	3.9	14.0	2.5
15	Oxygen control		92.1	2.0	24.0*	2.4	16.3	1.8
	42.2	5	90.7	1.2	13.7**	0.9	13.3*	0.6
		10	92.0	2.0	14.6**	2.3	14.3	1.8
		30	90.7	2.3	17.8**	1.1	15.7	1.2
		60	92.0	3.5	15.6**	3.0	14.5	0.8

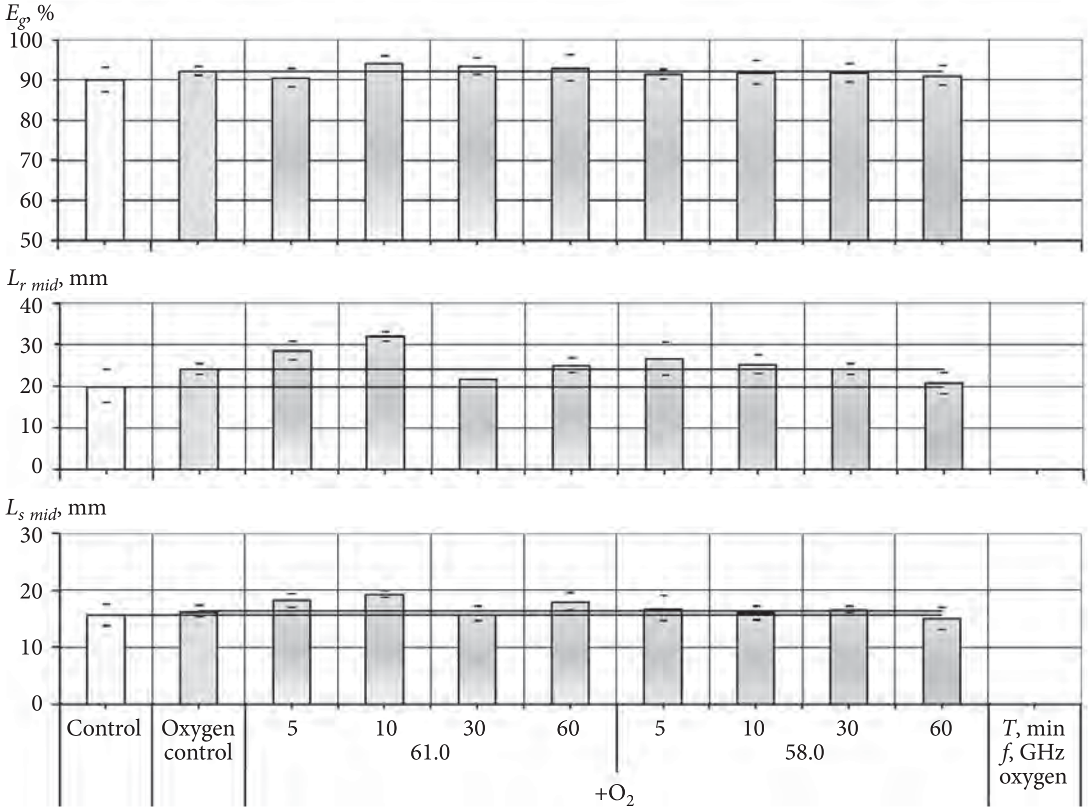

Fig. 1. Comparison of functional indices of "normal"-state wheat seeds against the time of the EMF exposure through the oxygen enriched and 61.0 and 58.0 GHz irradiated water

high functional indices and not pretreated with physical effects liable to affect the germination process. We will call them "normal"-state ones.

The changes in the functional indices of the "normal"-state wheat seeds after soaking them in EMF-irradiated and oxygen-enriched water are given in Table 1.

The seed soaking in oxygen-enriched water stimulates all functional indices of "normal"-state seeds. The root mean length is reliably 1.2 times that of the control set ($p < 0.05$). These figures referred to as "oxygen control" data were used to estimate effectiveness of the seed indirect exposure to EMF.

The 61.0 GHz indirect irradiation of wheat seeds reliably stimulates mean lengths of roots and seedlings at a short-length, 5- and 10-minute exposure by the factor 1.2 on the average. The results of a 10-minute exposure are more pronounced ($p < 0.001$). At a long-length, 30- and 60-minute EMF exposure, the changes remain within the confidence intervals. After a 30-minute exposure, a tendency appears to suppress the mean length of seedling roots (Fig. 1).

After the indirect seed irradiation in the 58.0 GHz band, a tendency is seen for E_g to decrease regardless of the length of exposure. A reliable suppression by the factor 1.2 with respect to the "oxygen control" state is only pronounced at the EMF exposure for 1 hour ($p < 0.05$) (Fig. 1).

The indirect irradiation of wheat seeds in the 42.2 GHz frequency band leads at any length of exposure to the suppression of all the studied indices with respect to the control ones related to the oxygen-enriched water soaking. The reliable values obtained at the estimation of sprout mean lengths get less by the factor 1.6 on the average ($p < 0.001$). The greatest suppression is observed after the 5-minute exposure: $L_{r\ mid}$ by the factor 1.2 ($p < 0.05$) and $L_{s\ mid}$ by 1.8 ($p < 0.001$) (Fig. 2).

Thus, the effectiveness of the exposure of "normal state" seeds to a low-intensity EMF through the oxygen enriched water depends on the signal frequency and exposure length.

A stimulating role of oxygen in the seed germination is noted. The oxygen activation in the 61.0 GHz frequency band additionally stimulates the functional indices of wheat seeds. Reliable re-

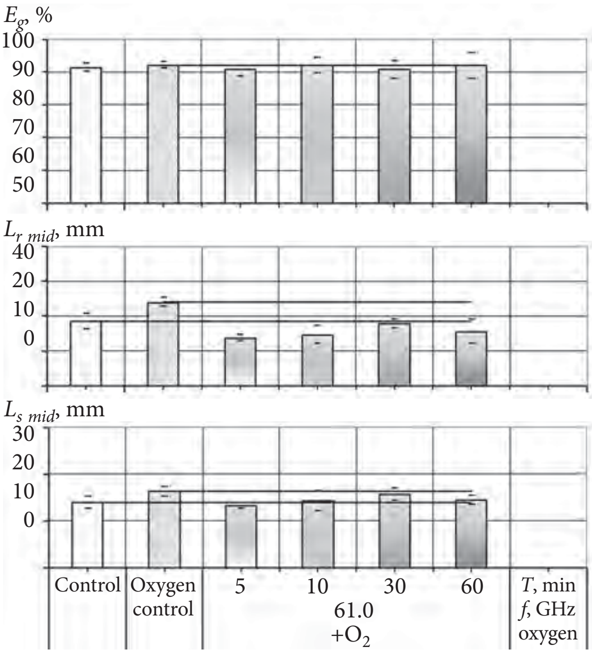

Fig. 2. Comparison of functional indices of "normal"-state wheat seeds against the time of the EMF exposure through the oxygen enriched and 42.2 GHz irradiated water

sults correspond to short, 5- and 10-minute exposures. Further lengthening of the exposure is of no use.

After the irradiation of oxygen-enriched water at the hydrogen absorption frequency 58.0 GHz, the electromagnetic effect efficiency decreases, exhibiting a further decrease as the signal exposure length increases.

The irradiation of the oxygen-enriched water at the ozone absorption frequency 42.2 GHz suppresses the wheat seed indices. The value of suppression varies with the length of the electromagnetic exposure.

The next series of experiments refers to wheat seeds in a "pathology" state achieved by pre-heating seats in a thermostat U-10 for 1 hour at 75 °C ("thermal control"). The results of the indirect exposure of "pathology"-state seeds to a low-intensity EMF through the irradiated and oxygen enriched water are shown in Table 2.

The soaking of "pathology"-state seeds in the oxygen-enriched water leads to a reliable recovery of the functional index E_g by the factor 1.1 ($p < 0.001$) and the indices $L_{r\ mid}$ and $L_{s\ mid}$ by the factor 1.3 ($p < 0.05$).

The soaking of "pathology"-state wheat seeds in the oxygen-enriched and 61.0 GHz irradiated water leads to their suppression with respect to the "oxygen control" state and to their stimulation with respect to the thermal suppression. The results with respect to the "oxygen control" are reliable and correspond to the 30-minute and 1-hour-long EMF exposures.

Table 2. **Comparison of functional indices of "pathological"-state wheat seeds after their indirect exposure to a low-intensity EMF through the irradiated and oxygen-enriched water (* – $p < 0.05$; ** – $p < 0.001$)**

Mode of exposure					Functional indices					
heat depression		O_2	EMF		E_g, %		$L_{r\ mid}$, mm		$L_{s\ mid}$, mm	
t, °C	T, min	T, min	f, GHz	T, min	E_g	RMS	$L_{r\ mid}$	RMS	$L_{s\ mid}$	RMS
Control					91.4	2.3	18.4	3.9	14.0	2.5
75	60	Thermal control			83.6^{**}	2.1	12.6^{**}	3.1	11.0^{**}	2.5
		15	Thermal control + O_2		89.3^{**}	3.4	16.6^{*}	2.6	13.9^{*}	2.7
			61.0	5	84.0^{*}	2.0	15.0	0.9	13.4	1.5
				10	86.0	2.0	16.7	0.5	13.3	0.2
				30	72.4^{**}	0.8	8.9^{**}	2.7	6.5^{**}	1.2
				60	72.0^{**}	0.0	6.7^{**}	0.3	5.3^{**}	0.6
			58.0	5	90.0	5.3	22.9^{*}	3.1	15.1	1.7
				10	84.0^{*}	2.0	19.3	4.7	14.2	3.0
				30	92.0	3.5	24.7^{**}	2.5	16.2	0.7
				60	94.7^{*}	1.2	21.0^{*}	4.7	14.0	2.2
			42.2	5	84.0^{*}	4.0	15.5	4.5	11.0	2.1
				10	89.3	4.2	14.6	1.5	10.6	1.1
				30	81.3^{*}	2.3	10.1^{**}	1.8	8.5^{*}	1.0
				60	92.7	3.1	17.6	1.3	12.2	0.2

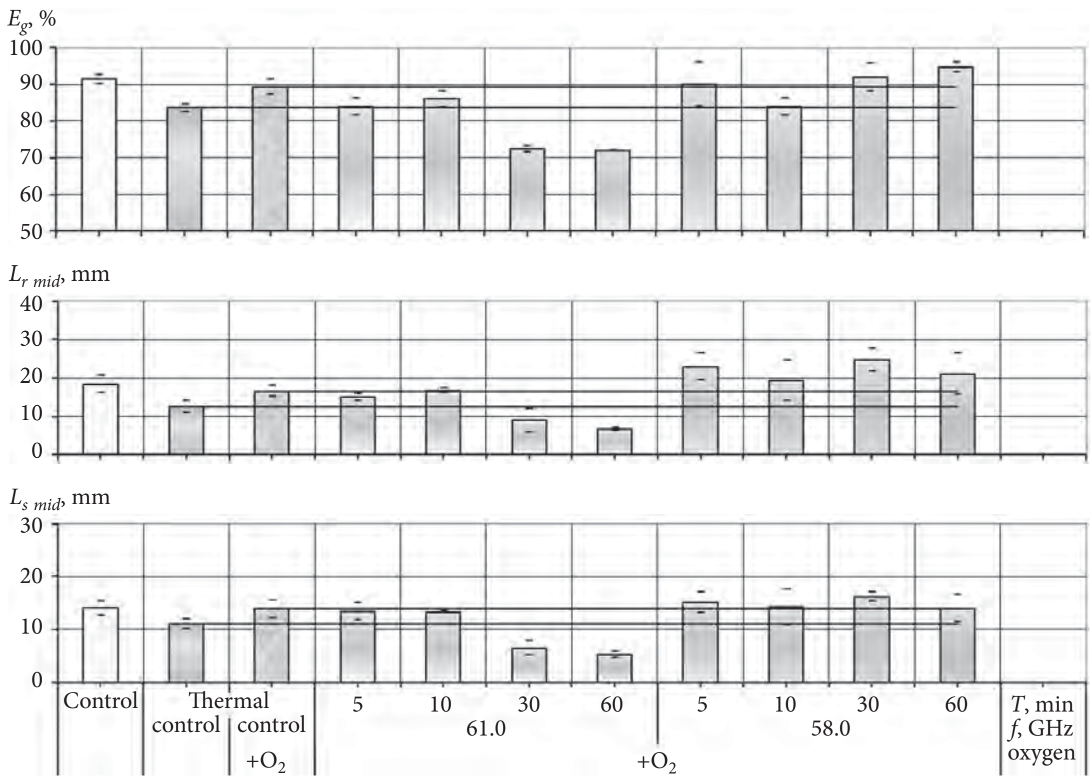

Fig. 3. Comparison of functional indices of "pathological"-state wheat seeds against the time of the EMF exposure through the oxygen-enriched and 61.0 and 58.0 GHz irradiated water

Here, E_g decreases by the factor 1.2 ($p < 0.001$), $L_{r\,mid}$ by the factors 1.9 and 2.5 ($p < 0.001$) and $L_{s\,mid}$ by the factors 2.1 and 2.6 ($p < 0.001$), respectively (Fig. 3). The stimulation of mean lengths of roots and seedlings in the "thermal control" case corresponds to short exposure lengths. A reliable $L_{r\,mid}$ increase by the factor 1.3 ($p < 0.05$) is seen and corresponds to a 10-minute exposure.

A preliminary 58.0 GHz irradiation of the oxygen-enriched water yields the E_g suppression by the factor 1.1 ($p < 0.05$) after a 10-minute exposure and the E_g stimulation by the factor 1.1 ($p < 0.05$) after an 1-hour exposure. The root mean length in the "oxygen control" case increases by the factor 1.3 on the average, with reliable results at a 5-minute exposure ($p < 0.05$), a 30-minute exposure ($p < 0.001$), and a 60-minute exposure ($p < 0.05$). For the mean length of seedlings, there is a general tendency to their stimulation within the statistical error. A comparison with the indices of thermally treated seeds suggests that in all the cases the recovery of the indices is reliable: E_g is recovered on the average by the factor 1.1 ($p < 0.05$), $L_{r\,mid}$ by the factor 1.8 ($p < 0.05$ and $p < 0.001$), and $L_{s\,mid}$ by the factor 1.4 ($p < 0.05$) (Fig. 3).

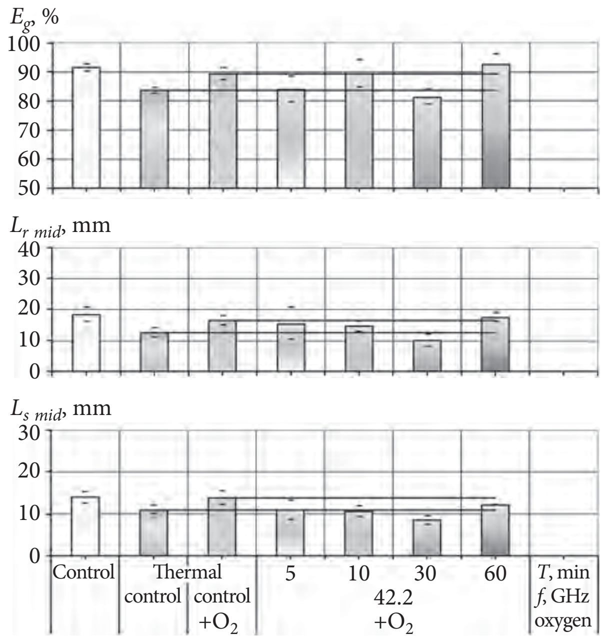

Fig. 4. Comparison of functional indices of "pathological"-state seeds against the time of EMF exposure through the oxygen-enriched and 42.2 GHz irradiated water

A 42.2 GHz 30-munute irradiation of water and its enrichment with oxygen clearly suppresses the seed functional indices: E_g by the factor 1.1

($p < 0.05$), $L_{r\ mid}$ by the factor 1.6 ($p < 0.001$), and $L_{s\ mid}$ by the factor 1.6 ($p < 0.05$) with respect to the "oxygen control" state. The 5-minute irradiation tends to suppress the mean length of roots and sprouts, with E_g reliably suppressed by the factor 1.1 ($p < 0.05$) (Fig. 4).

Thus, for soft-grade wheat seeds of 2015 harvest the following things can be stated. For wheat seeds with "pathology" due to the preliminary thermal treatment $t = 75$ °C, $T = 60$ min, the EMF exposure through oxygen enriched water leads to the dispersion growth depending on the signal frequency and length of exposure compared to the results obtained for seeds in the "normal"-state. Depending on the irradiation mode, either recovery of the lost properties of seeds or enhancement of their "pathology" state are observed.

The further water saturation with oxygen and its irradiation in the resonant frequency band of 61.0 GHz to imbibe dry wheat seeds with "pathology" leads to the recovery of the reduced indices in the case of short-length irradiation (5 and 10 minutes) or to the further suppression at longer (30 minutes and 1 hour) exposures.

The water irradiation at 58.0 GHz (the hydrogen absorption line frequency) and a simultaneous enrichment with oxygen exert stimulation effect on thermally suppressed seeds for all the electromagnetic exposure modes.

The water irradiation at 42.2 GHz (the ozone absorption line frequency) and a simultaneous enrichment with oxygen lead to the recovery of partially lost indices of wheat seeds depending on the signal exposure length.

Conclusions. A possibility to purposefully modify the functional indices of wheat seeds at their EMF exposure through the oxygen enriched water has been established and confirms the relevance of the water-dissipative and gas models of the EMF interaction with a substance.

A stimulating role of oxygen has been shown by means of additional oxygen enrichment of water for the imbibition of dry wheat seeds.

The gas model of the EMF interaction with a substance has been verified. Particular attention was given to the frequency bands 61.0 GHz (oxygen absorption line), 58.0 GHz (hydrogen absorption line) and 42.2 GHz (ozone absorption line). The biological response of wheat seeds to the carrier frequency has been observed at the seed EMF exposure through the oxygen enriched water in discrete frequency bands of the UHF range.

A non-monotonic behavior of the biological response versus the signal exposure time, which is individual for each frequency range, has been shown.

The differences in the EMF exposure effectiveness depending on the bio-object initial state, "norm" or "pathology" (the Initial Level rule) have been displayed. A possibility has been demonstrated to restore the functional indices of wheat seeds in "pathology"-state upon their EMF exposure through oxygen-enriched water.

We claim that the additional oxygen enrichment of water for seed imbibition and its 61.0 GHz EMF irradiation enable some recovery of the wheat seed functional indices at short-length exposures. Yet, at the same time, they facilitate the "pathology" state for long-length EMF exposures, which can be explained by the formation of radicals. The irradiation in the 58.0 GHz frequency band enhances the effect of recovery, while the 42.2 GHz irradiation makes this recovery less pronounced.

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ОСОБЛИВОСТІ РЕЗОНАНСНОГО ВПЛИВУ МІКРОХВИЛЬОВОГО
ВИПРОМІНЮВАННЯ НА НАСІННЯ ПШЕНИЦІ ЧЕРЕЗ ЗБАГАЧЕНУ КИСНЕМ ВОДУ

Предмет і мета роботи. Розглянуто особливості цілеспрямованої модифікації функціональних показників насіння пшениці шляхом його замочування у воді, попередньо опроміненій низькоінтенсивним електромагнітним полем (ЕМП) і збагаченій киснем. Мета — дослідити ефективність опосередкованого через збагачену киснем воду впливу низькоінтенсивного ЕМП у дискретних смугах надзвичайно високочастотного діапазону на насіння пшениці залежно від його початкового стану («норма» або «патологія»).

Методи і методологія роботи. Робота є експериментальною. У ній були застосовані апробовані радіофізичні, радіотехнічні, хімічні методи та засоби впливу. Як джерела опромінення використовувались генератори Г4-141 (37,5…53,57 ГГц) і Г4-142 (53,57…78,33 ГГц). Кисень отримували в результаті реакції розчину перекису водню з перманганатом калію. Збагачення води киснем відбувалося під час її опромінення. Верифікація опосередкованого впливу ЕМП оцінювалася за зміненням функціональних показників насіння: енергії проростання, середньої довжини коренів і проростків у кожній вибірці.

Результати роботи. Встановлено можливість модифікації функціональних показників насіння пшениці шляхом його замочування у воді, попередньо опроміненій ЕМП і збагаченій киснем. Виявлено залежність ефективності впливу від стану насіння («норма» або «патологія») і, зокрема, можливість відновлення втрачених властивостей в стані «патологія». Показано роль кисню, що міститься у воді, на процес проростання насіння. Показано залежність ефективності опосередкованого через збагачену киснем воду впливу ЕМП від частоти та експозиції сигналу, а також від загального енергетичного навантаження.

Висновок. Встановлено, що вплив ЕМП на речовину, включаючи живе, можливий через воду. Підтверджено актуальність водно-дисипативної моделі впливу ЕМП на речовину, в рамках якої вода — одна з мішеней, здатних змінювати свої властивості під дією ЕМП. Це знаходить непряме підтвердження при оцінці зміни стану насіння, що замочуються в опроміненій воді. Проведено верифікацію газової моделі взаємодії ЕМП з речовиною. Показано можливість активації кисню при резонансному опроміненні.

Ключові слова: *електромагнітне поле, насіння пшениці, вода, опосередковане опромінення, кисень, резонанси газів.*