BIOIMPACT OF HYPOMAGNETIC FIELDS

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Abstract

Hypomagnetic fields (HMF), or nearly zero magnetic fields, are fields with a value of magnetic flux density lower than the Earth's geomagnetic field. The effects of these so-called weak magnetic fields can manifest in living organisms by influencing biological functions such as the circadian system, calcium balance in cells, DNA methylation, concentration of reactive oxygen species, as well as changes in metabolic and developmental processes. This article describes how HMF affects selected cellular structures through specific exposure parameters, whose selective impact has been verified on the proliferative activity of the yeast strain Saccharomyces cerevisiae. In 25 experiments, the inhibitory effect of a time-varying magnetic field at a level of 0.365 μT was confirmed, which corresponds to the magnitude of magnetic flux density in the vicinity of 100 kV power lines. Global organizations also point out the possible correlation between HMF generated by 50 Hz power lines and various diseases, particularly childhood leukemia.

Keywords

Hypomagnetic fields, Saccharomyces cerevisiae, exposition of magnetic field

Introduction

Living beings are born and grow in the presence of physical fields, such as the gravitational or geomagnetic field (GMF). On average, the amplitude of the GMF is approximately 50 μT. A certain part of the overall population's exposure to magnetic fields is primarily composed of hypomagnetic field (HMF), as documented in Table 1, which displays actual measured action values in the external environment near sources of magnetic fields (MFs).

MF with amplitudes lower than the GMF, also known as nearly zero field [1], has been shown to have various biological effects. HMF exposure has been shown to affect the levels of reactive oxygen species (ROS), alter calcium metabolism, and change gene expression through epigenetic mechanisms, any of which can lead to the development of cancer and/or other diseases or physiological changes [2–5].

Studies suggest that HMF can influence circadian rhythms, as well as learning and memory processes [6, 7]. These effects have been observed in genetics, developmental processes, and neuronal activity in the brain.

Table 1: Values of measured quantities in the vicinity of electrical lines.

Measured object	***E* (V/m)**	***B* (μT)**
22-kV Power Line	0.065–109.450	0.001–0.023
110-kV Power Line	0.2–775	0.046–0.365
22/0.4-kV Transformer Substation in a Building	0.1–0.98	0.17–4.63
Proximity to a 22/0.4-kV Transformer	0.12–86.25	0.06–0.71
Standalone 22/0.4-kV Substation	0.35–275.5	0.02–3.985
Proximity to a 22-kV Overhead Line Termination Point	15.5–52.1	0.166–0.314
Apartments near a 110-kV Substation	1.37–3.92	0.128–0.54
Office Space near 110/22-kV Transformers	0.779–4.652	0.087–0.450

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HMF has demonstrated the ability to block the inhibitory effects of physiological concentrations of melatonin and tamoxifen on the growth of human breast cancer cells [4]. The inhibitory effect was observed at amplitudes of a time-varying field ranging from 0.5 μT to 1.7 μT and a frequency of 60 Hz.

HMF has been found to affect the enzymatic activity of ornithine decarboxylase (ODC) in cultured fibroblast cells. Increased ODC activity was observed at amplitudes ranging from 1 μT to 20 μT and a frequency of 60 Hz, with significant doubling of ODC activity at 7 μT [4].

Epidemiological studies have also provided evidence of the effects of HMF. There is a consistent association between childhood leukemia and 50–60 Hz magnetic fields generated by power lines, leading the International Agency for Research on Cancer to classify extremely low-frequency electromagnetic fields (ELF-EMF) as potentially carcinogenic to humans. Long-term exposure to ELF-EMF in the range of magnetic flux densities amplitudes from 0.1 μT to 0.4 μT has been associated with childhood leukemia, childhood brain tumors, and Alzheimer's disease [8–10]. A meta-analysis of six studies investigating the distance between residences and power lines conducted by Kheifets et al. found a higher likelihood of cancer occurrence (odds ratio, OR) of 1.6 for distances from 0 to 50 m compared to individuals living far from power lines. The OR was 1.3 for distances from 50 m to 100 m and 1.2 for distances from 100 m to 200 m [11].

Although some epidemiological findings raise an association between EMF exposure and the incidence of childhood leukemia, brain tumors, or neurodegenerative disorders, other evidence suggests therapeutic properties including significant reductions in the growth of various tumors such as breast cancer, gastrointestinal cancer, sarcoma melanoma, and hepatoma [12–14]. In addition, ELF-EMF can prolong survival and improve overall symptoms in patients with advanced malignancies [15, 16], possibly improving the effects of chemotherapy [17].

These experimental and empirical pieces of evidence provide a strong scientific basis and motivation for further research into the biological effects of various physical parameters of HMF, prove amplitude and frequency selective biological response [18] and highlight the need of "precautionary principle" (ALARA) application.

This study aims to contribute to the understanding of these effects by investigating the impact of time varying HMF on the proliferative activity of *Saccharomyces cerevisiae* cells via their exposition to chosen action value of magnetic field produced by electric power lines, which is well below the recommendations of national, or international standards and specifications.

Materials and Methods

To this study, an exposure setup and the biological part of the experimental protocol described by Judáková [19] were used. The experimental section consists of 5 experiments, each with 5 samples exposed to HMF, 5 control samples, and 1 experiment without HMF exposure, serving as a control experiment to verify the results. The exposure conditions were chosen to reflect HMF corresponding to the action value of magnetic flux density measured in the vicinity of power electric lines. During the experiments, *Saccharomyces cerevisiae* cells were exposed to HMF with the same physical parameters: a 50 Hz sinusoidal current signal corresponding to a magnetic flux density value of B_{AC} = 0.365 μT (selected from Table 1). The exact value of electric current was established on the base of Biot-Savart law, schematically depicted on Fig. 1, representing the real model of used magnetic field applicator, and mathematically expressed in Equation 1.

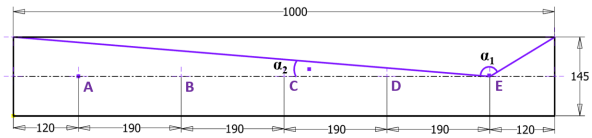

Fig. 1: Biot-Savart law definition corresponding to exposure setup.

$$B_z = \frac{\mu_0 NI}{2l}(cos(\alpha_2) - cos(\alpha_1)), \quad (1)$$

where B_z is chosen magnetic flux density, I represents the current flowing through the coil, N is the number of turns of winding (2000), l is the length of the coil (1 m), and μ_0 is the permeability of vacuum ($4\pi \cdot 10^{-7}$ N·A^{-2}).

The calculation resulted in effective value of I = 0.04883 A, which serves as driving current fed into the exposure coil as presented on Fig. 2.

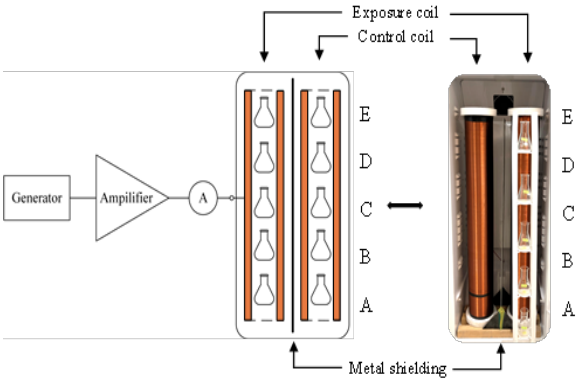

Fig. 2: The exposure setup used in the experimental part of this contribution, where the letters E–A corresponds to position of samples.

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Additionally, all experiments were conducted under the same conditions, including an incubator temperature of 30 °C, room temperature of 23 °C, and the same duration of exposure. The experiments were performed within a time interval of four hours. The biological response of the cellular system was evaluated using the growth dynamics coefficient X, presented on Fig. 3, which represents the reciprocal ratio of growth between the control (C) and exposed (E) samples. This coefficient indicates how many times the exposed sample's growth differs from the growth of control sample.

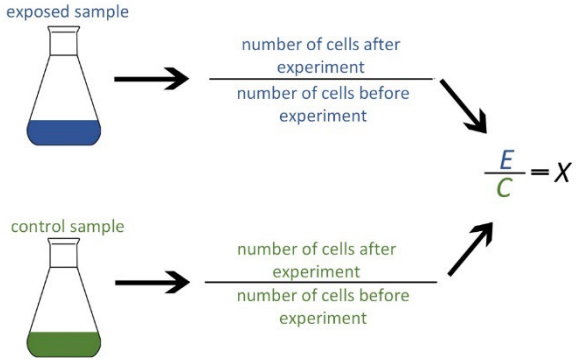

Fig. 3: The method for determining the effect of MF.

The yeast cells were counted on ten squares of a Bürker chamber, and mean value of these counts is taken into the coefficient calculation. The short life cycle and genetic characteristics of *S. Cerevisiae* make it suitable for studying quantum biological pathways in eukaryotic cells. As stated by Liu [20], these single-celled fungus microorganisms share 23% of homologous genes with humans. Yeasts are cultivated in YPD (Yeast-Extract-Peptone-Dextrose) solution under acidic conditions to prevent bacterial contamination. The growth medium comprises 1% yeast extract, 2% peptone, 2% glucose, and 95% distilled water. Before conducting the experiments, a pre-cultivation process occurs in a laboratory shaker for 24 hours to attain a specific initial concentration of microorganisms. Subsequently, the experimental solutions are prepared through dilution. The cultivation period of these solutions lasts for 8 hours, focusing on the exponential growth phase. This phase is characterized by the absence of cell death, consistent cell size, and the shortest generation time, as stated in [21]. This growth phase is crucial for detecting any modifications in cell cultures during exposure.

Results

In the five experiments conducted within the experimental setup, there were five samples in both the exposure and control coils, resulting in a total of 25 samples. The average value for the control samples was determined to be 4.56 with a standard deviation of 1.17%, while the average value for the exposed samples was 2.82 with a standard deviation of 0.95% (Fig. 4).

A noticeable difference of –38.06% can be observed between the exposed and control experiments. To perform a statistical analysis, a T-test was conducted, resulting in a p-value of $5.91 \cdot 10^{-7}$. The hypothesis regarding the statistical significance of the difference between the mean values of the samples is confirmed at a significance level higher than 0.01.

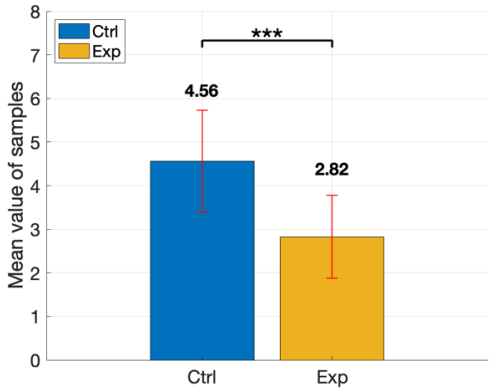

Fig. 4: Mean values of control and exposed samples, n=25 for both experiments.

Subsequently, the control experiment was conducted, and the results are presented in Fig. 5, where the *Saccharomyces cerevisiae* cells were present in both magnetic field applicators without the exposure being turned on.

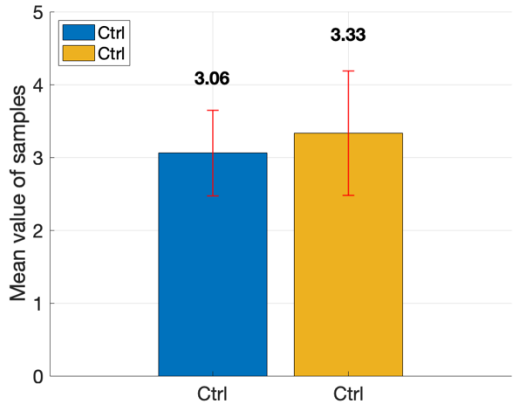

Fig. 5: Mean values of two control experiments, n=5 for both experiments.

The effect between the two control experiments was observed. The hypothesis that the cells grow similarly in both coils was confirmed after conducting a T-test, resulting in a p-value of 0.57. This indicates that there is no statistically significant effect observed between

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the mean values of the samples. In this experiment, the statistical sample consists of 5 data points, showing an 8.95% difference between the control samples. However, due to the standard deviations (0.59 for the blue column and 0.85 for the yellow column), the statistical significance is negligible.

Discussion and Conclusion

The yeast strain *Saccharomyces cerevisiae* was exposed to the HMF with European power grid frequency of 50 Hz and an effective value of $\boldsymbol{B}_{AC} = 0.365$ μT, which corresponds to the amplitude of magnetic flux density near a standard 110 kV power line. Out of the 25 experiments conducted, an inhibitory effect was observed in 24 of them. A T-test was used for statistical evaluation, which rejected the null hypothesis and accepted the alternative hypothesis, indicating that the applied HMF parameters during the 4-hour exposure had a statistically significant biological effect, which should be considered as an acute effect of continuous HMF exposure.

A control experiment was used for comparison, where the yeast cells were placed in the field applicators in the incubator for the same 4-hour time interval but without the stimulating signal. The same hypothesis was used for statistical analysis, and it was not rejected, suggesting that there was no significant biological effect observed among the control samples.

Given that this paper deals within the range of extremely low frequencies, such as the 50 Hz frequency, it's plausible to consider injection-locking mechanisms in relation to J-coupling values when proteins or molecules are subjected to NMR Spectroscopy. In this scenario, the J values, measured in Hertz, could potentially become synchronized with higher or lower frequencies, related to an oscillator in electrical engineering. This synchronization could result in the exposed system's frequency becoming locked to different energy levels. One example of a molecule that might exhibit a J value around 50 Hz in certain cells is lactate [22]. Lactate is produced as a byproduct of anaerobic metabolism, which is often upregulated in cancer cells due to their increased glycolytic activity, known as the Warburg effect [23]. In the context of NMR spectroscopy, lactate can exhibit a J-coupling between the protons on the CH3 (methyl) group and the neighboring CH (methine) group. This coupling can result in a J value around 50 Hz. Specific J value of lactate can vary depending on factors such as pH, temperature, and the presence of other molecules. Like cancer cells, yeast cells can undergo anaerobic metabolism, particularly in environments where oxygen is limited. During anaerobic metabolism, yeast cells convert glucose into pyruvate through glycolysis, and then pyruvate is further metabolized to lactate to regenerate NAD+ for continued glycolysis. Locking the J-coupling values might turn into changes in chemistry of molecules thus changing the proliferation rate of cells.

Another possible explanation about how HMF could impact yeast cells involves a feedback mechanism with a time delay. Alterations in the frequency, phase, or amplitude of the electromagnetic field could lead to changes in the behavior of yeast cells, related to how adjustments in a feedback loop affect the output of an operational amplifier in electrical engineering. By modifying the feedback mechanism, it's conceivable that we could shift the cellular response to the field from a slowdown (attenuation) to a speeding up (acceleration) of the growth rate [24].

For our experiments, implementing double-blinding is unnecessary for several reasons. Firstly, our experiments primarily entail observational data collection (using Burker chambers), rendering the application of blinding impractical given the nature of the intervention. Additionally, our study involves non-human subjects, further diminishing the need for double-blinding. This paper use protocols followed by other significant studies in the field of EMF and cancer cells [25, 26], where double-blinding is deemed unnecessary. Furthermore, logistical constraints and limited human resources pose challenges that make implementing double-blinding impractical during experimental evaluation and development.

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