

# Studying of the effect of THz radiation on cells of the thermophilic bacterium *Geobacillus icigianus*

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**Key words:** terahertz radiation; *Geobacillus icigianus*; transcriptome

**Motivation and Aim:** As the applications of non-thermal terahertz (THz) radiation expand, especially in biomedicine, evidence is accumulating that this type of radiation can influence both biological molecules directly and cellular processes in general. Moreover, there is evidence of changes in intracellular processes under the influence of THz radiation at the transcription level. Thus, in the *E. coli* cell, THz irradiation changes the expression of genes involved in protection from oxidative stress, maintaining the homeostasis of transition metals, amino acid metabolism, etc. [1–4]. However, identifying the biological effects of THz radiation in thermosensitive organisms is associated with a number of technical difficulties, one of which is maintaining optimal temperature [5]. This study analyzed the effect of THz radiation on gene expression in the cells of the thermophilic bacterium *Geobacillus icigianus*, which is adapted to a wide temperature range from 50 to 75 °C [6]. It was previously noted that THz irradiation did not lead to the appearance of heat shock proteins in its cell [7].

**Methods and Algorithms:** The experiments were carried out on the basis of a terahertz free electron laser at the Siberian Center for Synchrotron and Terahertz Radiation (Institute of Nuclear Physics SB RAS). This research was supported in part through computational resources of HPC facilities at collaborative center “Bioinformatics” ICG SB RAS. Cells in LB medium in a specially designed cuvette were irradiated for 15 min with THz radiation with a power density of 0.23 W/cm<sup>2</sup> and a wavelength of 130 μm. To identify genes that change their expression level under the influence of THz radiation, the results of previously conducted whole-genome sequencing of the *G. icigianus* genome were used. Analysis of the effect of THz radiation on the cell transcriptome was carried out using RNA sequencing.

**Results:** A comparative analysis of the transcriptome of *G. icigianus* cells immediately after THz irradiation (2.3 THz, 15 min.) and 10 min after the end of irradiation showed the absence of activation of heat shock protein genes and showed a negative effect of THz irradiation on the gene systems that control the growth of the bacterium and the structure of its cellular wall, demonstrated inhibition of transcription of a number of genes, the products of which are involved in redox reactions and protection from oxidative stress, genes of the chaperone protein ClpB and the DNA repair system protein RadA, as well as genes of the two-component system for phosphorylation of arginine residues using McsB kinase. The latter is critical in regulating the cellular response to oxidative stress, marking proteins and their subsequent degradation by the Clp protease,

as well as regulating processes such as cell motility and competence. At the same time, activation of transcription of genes for the metabolism of sugars, fructose and xylose, synthesis of lactic acid, transport of oligosaccharides and cyclodextrins was observed, which may be a cell response to THz irradiation associated with a general inhibition of metabolism observed during this period at the proteomic level [7], and aimed at using additional carbon sources. The most sensitive to THz irradiation were the gene systems for maintaining the homeostasis of transition metals – copper, iron and zinc, the inhibition of the expression of which increased significantly 10 min after the end of exposure. Blocking the expression of genes for the copper export and iron import systems under the influence of THz irradiation may be a precursor to the development of toxic stress in *G. icigianus* cells, leading to destabilization of the function of proteins containing Fe/S clusters in their structure.

**Conclusion:** Transcriptomic analysis of irradiated *G. icigianus* cells confirmed the non-thermal nature of THz radiation [7], as well as the sensitivity of gene systems for maintaining transition metal homeostasis to irradiation, also observed in *E. coli* [2]. Unlike *E. coli* [1], cells of the thermophilic bacterium *G. icigianus* demonstrated rapid restoration of the activity of gene systems for anti-stress protection of DNA structure and proteins after THz irradiation.

**Funding:** The study is supported from the Kurchatov Genomic Center of the Institute of Cytology and Genetics SB RAS (No. 075-15-2019-1662) and the Ministry of Science and Higher Education of the Russian Federation (No. FWNR-2022-0022).

## References

1. Demidova E.V., Goryachkovskaya T.N., Malup T.K., Bannikova S.V., Semenov A.I., Vinokurov N.A., Kolchanov N.A., Popik V.M., Peltek S.E. Studying the non-thermal effects of terahertz radiation on *E. coli*/pKatG-GFP biosensor cells. *Bioelectromagnetics*. 2013;34(1):15-21. doi 10.1002/bem.21736
2. Demidova E.V., Goryachkovskaya T.N., Mescheryakova I.A., Malup T.K., Semenov A.I., Vinokurov N.A., Kolchanov N.A., Popik V.M., Peltek S.E. Impact of terahertz radiation on stress-sensitive genes of *E. coli* cell. *IEEE Transact Terahertz Sci Technol*. 2016;6(3):435-441
3. Serdyukov D.S., Goryachkovskaya T.N. et al. Study on the effects of terahertz radiation on gene networks of *Escherichia coli* by means of fluorescent biosensors. *Biomed Opt Express*. 2020;11(9):5258-5273. doi 10.1364/BOE.400432
4. Serdyukov D.S., Goryachkovskaya T.N., Mescheryakova I.A., Kuznetsov S.A., Popik V.M., Peltek S.E. Fluorescent bacterial biosensor *E. coli*/pTdcR-TurboYFP sensitive to terahertz radiation. *Biomed Opt Express*. 2021;12(2):705-721. doi 10.1364/BOE.412074
5. Sun L., Zhao L., Peng R.Y. Research progress in the effects of terahertz waves on biomacromolecules. *Mil Med Res*. 2021;8(1):28. doi 10.1186/s40779-021-00321-8
6. Bryanskaya A.V., Rozanov A.S., Slynko N.M., Shekhovtsov S.V., Peltek S.E. *Geobacillus icigianus* sp. nov., a thermophilic bacterium isolated from a hot spring. *Int J Syst Evol Microbiol*. 2015;65(Pt. 3):864-869. doi 10.1099/ijms.0.000029
7. Bannikova S., Khlebodarova T., Vasilieva A., Mescheryakova I., Bryanskaya A., Shedko E., Popik V., Goryachkovskaya T., Peltek S. Specific features of the proteomic response of thermophilic bacterium *Geobacillus icigianus* to terahertz irradiation. *Int J Mol Sci*. 2022;23(23):15216. doi 10.3390/ijms232315216