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Original Paper

ESTABLISHMENT OF BIOTESTING SYSTEM TO STUDY FEATURES OF INNOVATIVE MULTIFUNCTIONAL BIOTEXTILE

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*An established biotesting system designed to discover specific features of innovative multifunctional biotextile, encompassing integrated silica dioxide and succinite (Baltic amber) particles, is founded on reproducible, reliable, and relatively fast methods. The main idea starting this study was to create a system of test methods devoted to identification of specific features of biotextile materials designed to preserve living organisms from adverse environmental factors like enhanced electromagnetic radiation of different frequencies, without use of vivarium animals. Cultures of the freshwater macrophyte duckweed (*Lemna minor*) line* Sta2 *and fruit flies (*Drosophila melanogaster*) were chosen as model systems suitable for the study of the influence of electromagnetic field (EMF) radiation. The experiments showed changes of phenotypic features and growth parameters of test objects, as well as induction of point mutations of DNA (for example, insertions or deletions in chloroplast DNA and nucleotide substitutions in nuclear genes). The responses of test organisms induced by EMF were studied using microscopy, flow cytometry, and DNA sequencing methods. On the cell level, a new fast flow cytometry method for biotextile testing was developed: immature gametic (pollen) cell cultures were used as a highly sensitive model system (plant gametic cell response is comparable to human neutrophil response) to study the influence of EMF radiation. The method was based on the measurement of differences of fluorescence intensity between group of cells experimentally affected by EMF radiation and non-affected cells.*

Keywords: *silica dioxide nanoparticles,* Lemna minor*, electromagnetic field (EMF) radiation,* Drosophila melanogaster*, model organisms.*

INTRODUCTION

Due to the rapid development and widespread use of modern technologies, electromagnetic interference is becoming an increasing problem (Biao *et al*., 2018; Gong *et al*., 2018; Gurusiddesh *et al*., 2018; Jiang *et al*., 2019), and protection of the human body from electromagnetic interference (EMI) has become increasingly important in recent decades (Blachowicz *et al*., 2023). Artificially generated electromagnetic fields (EMF) can have a variety of effects not only on living organisms, but can also affect or degrade the performance of other electronic devices, causing fluctuations in the operation of equipment, loss of stored data, etc. (Li *et al*., 2018; Duc and Bilik 2023). EMF in some frequencies, for example UV waves, can affect biological processes (Erogul *et al*., 2006; Engels *et al*., 2014; Omer, 2021; Kuila *et al*.,

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2023). The growing impact on human health, especially in cases when people become increasingly exposed to electromagnetic radiation, creates the need to expand the EMF shielding material range (Blachowicz *et al*., 2023; Liu *et al*., 2020).

The development of textiles and clothing has been playing an increasingly important role as ways to protect employees affected by enhanced EMF radiation, as well as to shelter ordinary human exposed to EMF, especially in the most urbanised areas (Chatterjee *et al*., 2020; Liu *et al*., 2020). As electromagnetic pollution deteriorates, it can become a public health challenge, with the use of EMF shielding materials becoming an integral part of new materials of the future (Liu *et al*., 2020). Protecting clothing against EMF is the most convenient way of protecting a person from increasing EMF radiation. This is especially important for employees working in places with high electromagnetic radiation.

This study was aimed to develop a biotesting system using test organisms and cell cultures to determine the ability of biotextile to protect test organisms after experimental exposure in electromagnetic fields. The main research task was to develop biotesting methodologies and determine properties of nanoparticles and other raw materials incorporated into biotextile, as well as to reveal specific features of produced biotextile material. The obtained results based on responses of test organisms should be comparable and repeatable, as well as production of such materials should have low cost. The test methods were selected and implemented to be able to determine the effect of active substances incorporated into biotextile, such as nanoparticles, and to test the properties of the new material as a manufactured product. To produce a new type of biotextile with the desired properties mitigating adverse impact of EMF radiation (Grauda *et al*., 2015; Ļašenko *et al*., 2016), various natural fibres (linen, wool, cotton) as well succinite and silicon nanoparticles were used to develop the composite fibres. Succinite nanoparticles (400–800 nm) at various concentrations (1%, 3%, 5%) alone or in combination with silicon dioxide nanoparticles were embedded in the polyamide (PA6) structure or silicon dioxides nanoparticles by the method sol-gel coated on a fabric. Previous studies revealed that succinite possesses specific properties, i.e. ability to increase parameters of cell activity, and it was shown that its influence on tested cells was harmless (Grauda *et al*., 2015; 2021). There is no information about the use of biotextile materials as coatings increasing protection against adverse effects induced by increased UV and low frequency EMF radiation. The basic knowledge gained after studies of multivariate effects of EMF on eukaryotic cells and model organisms, were used to improve study methods and to adapt developed methods for applications in new areas.

Previously (Grauda *et al*., 2015), gametic cells were used as a highly sensitive model system to identify the effects of environmental factors on cells. It was therefore assumed that the modification of the test method could be applied to reveal protection capacity of biotextile containing succinite and silicon nanoparticles (Grauda *et al*., 2021) using test organisms and cell cultures affected by the UV-B and low frequency electromagnetic field (LF-EMF) radiation. Consequently, the aim of the study was to create a biotesting system that allows to determine specific features of the multifunctional biotextile, based on reproducible, reliable and relatively fast methods.

MATERIAL AND METHODS

Material for textile biotesting was produced by JLU Technologies Ltd, Latvia (Viļuma-Gudmona *et al*., 2021).

We chose to study responses of cyclamen (*Cyclamen persicum*) cells by performing testing based on flow cytometry methods (FCM) as one of the most rapid study methods enabling recording of changes of cell parameters after UV-B irradiation and for ELF-EMF impact assessment (Fig. 1).

For testing of protecting properties of newly developed biotextile, plant gamete cells in the mononuclear stage of development were affected by ultraviolet radiation at 365 nm wavelength generated by a UV-B lamp fixed 30 cm above the Petri plates with affected cells. The method is based on determining changes in relative fluorescence (RF) using a flow cytometer and recording changes in the cell membranes and organelles. Gametic cells placed in Petri plates coated with biotextile materials were exposed to experimentally generated UV-B radiation for one and three hours.

The testing procedure was as follows:

Petri plates 35 mm in diameter with approximately 100,000 cells in MS (Murashige and Scoog) medium (Murashige

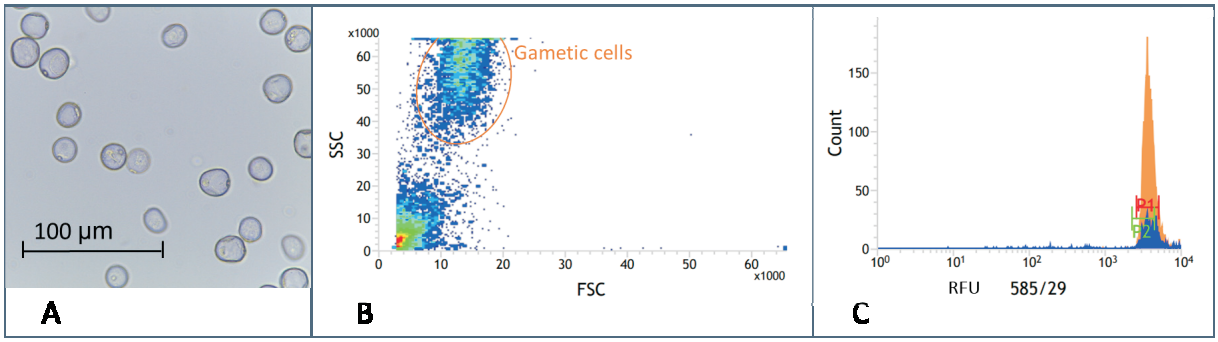


Fig. 1. Isolated gametic cells in the middle of uninucleate developmental stage (A), FCM density plot (B), cells relative fluorescence, log scale (C).

and Skoog, 1962) were coated with one to the following biotextiles:

1) fabric or knitwear with composite amber fibres containing 1% succinite (CAS 9000-02-6) nanoparticles;

2) fabric or knitwear with the composite amber fibres containing 1% succinite and 1% SiO_2 (CAS 7631-86-9) nanoparticles;

3) fabric or knitwear with composite amber fibres containing 1% succinite and 2% SiO_2 nanoparticles;

4) fabric or knitwear with composite amber fibres containing 1% succinite and 3% SiO_2 nanoparticles.

Silicone (CAS 9006-65-9) was used to coat SiO_2 nanoparticles (10 nm) on fabrics using the sola-gel method. Exposure to UV-B irradiation was continued for 1 h and 3 h. Tests were performed in four replicates for each fabric type. The source of the EMF, UV-B lamp, generating UV radiation at 365 nm wavelength, was placed 30 cm above the Petri plates.

A BD FACSJazz® cell sorter (BD Biosciences, USA) was used for flow cytometry analysis. Changes in cell fluorescence after irradiation with a blue laser (488 nm) (Grauda *et al*., 2015) were studied. Differences of cell relative fluorescence units (RFU) reflects changes in cell life parameters. MS Excel software was used for statistical analysis; the *p*-value threshold was < 0.05.

To determine the protective properties of biotextile materials, effects of experimentally generated low-frequency electromagnetic fields on test organisms and cell cultures were evaluated using a test system that includes a low frequency electromagnetic field (LF-EMF) generated by Helmholtz coils (Fig. 2). Petri plates with test specimens were placed inside the system consisting of two Helmholtz coils, producing a region of nearly uniform magnetic field (450–518 μT). An alternating magnetic field was created by a Helmholtz coil system (Fig. 2) consisting of two coils with 189 turns of isolated copper wire (diameter 0.7 mm), each with radius r = 25 cm as well. The distance between coils was 25 cm. For creation of alternating electric current in the Helmholtz coils, a signal generator-oscilloscope PCSGU250 and linear amplifier were used. A sinusoidal 50 Hz electric current was used in this study. Operation of the system was performed by a personal computer with installed software PcLab 2000.

The fruit fly (*Drosophila. melanogaster*) laboratory line 'Origon-R' was used to perform a modified survival test (Weisman *et al*., 2014) designed to study protective capacity of biotextile (Grauda *et al*., 2021). Two generations of *D. melanogaster* were exposed to LF-EMF (50 Hz, 450–518 μT) in this testing cycle.

The axenic laboratory line *Sta2* (Žagata *et al*, 2023, this issue) of the freshwater macrophyte duckweed (*Lemna minor*) was used in experiments as additional test organism to assess the effect of LF EMF on phenotype and growth parameters of test objects, as well as on nucleotide substitutions, insertions or deletions potentially generated by LF-EMF in DNA sequences of selected genes. For DNA extraction, whole plants of *L. minor* with fronds and roots were ground in liquid nitrogen and total DNA was extracted using a DNeasy Plant Mini Kit (QIAGEN) according to manufacturer's protocol. DNA extracts were diluted to a final concentration of 10 ng/μl in distilled water and stored at –20 °C until use.

Point mutations were determined in plants of *L. minor* line *Sta2* grown in Petri plates, which were experimentally exposed to LF-EMF generated by a mentioned Helmholtz coil (Fig. 2). Half of *L. minor* plants were not placed in the Helmholtz coil system but were grown in the same experimental room under same conditions considered it a control group. Extracted DNA of each *L. minor* plant, representing affected by LF EMF or control plant, was used for amplification and sequencing of partial fragments of catalase, glutathione peroxidase (*GPx*) and ascorbate peroxidase (*APx*) genes to identify new point mutations. The PCR programme was 5 min at 94 °C; followed by 35 cycles at 94 °C for 45 s, specific primer's annealing temperature for 45 s, elongation step at 72 °C for 1 min, and final extension at 72 °C for 10 min. The PCR amplicons were purified with exonuclease I and FastAP Thermosensitive Alkaline Phosphatase (Thermo Scientific) and then sequenced using a 3500 Genetic Analyser (Applied Biosystems). The sequenced DNA fragments were aligned using the MUSCLE option in MEGA-X (Kumar *et al*., 2018) to score point mutations generated in the group affected by LF-EMF or in the control group.

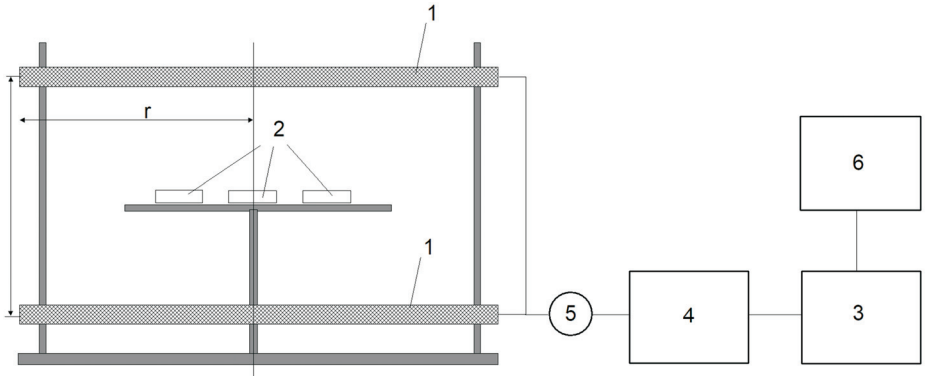


Fig. 2. Helmholtz coil and associated equipment used for testing organism's exposure to extremely low frequency (50 Hz) electromagnetic fields. 1, Helmholtz coil; 2, plastic tubes or Petri plates with specimens fixed in the central area between the coils; 3, signal generator; 4, linear amplifier; 5, ampere meter; 6, computer.

RESULTS

The study showed that one hour of incubation was sufficient to determine the effect of UV-B on tested cells and to reveal protective properties on of fabrics. After three hours of incubation, the total RF of cells decreased in all groups, possibly because some cells stop developing. It was found that 1% SiO_2 nanoparticles incorporated into coating increased protection properties of biotextile fabrics against UV-B most efficiently (Fig. 3, A). Type of coating used to attach the SiO_2 nanoparticles to the fabric also affected the protective properties of fabrics (Fig. 3, B). Similar results were obtained using gamete cells to test the protective properties of fabrics against LF-EMF (50 Hz, 450–518 μT).

The biotextile materials with amber yarn and covered with 1% SiO_2 nanoparticles suspension provided the best protection against UV-B irradiation: survival percentage of *D. melanogaster* larvae after irradiation with UV-B was 98%. The survival of *D. melanogaster* larvae grown in tubes covered with biotextile materials with 2 and 3% of SiO_2 were significantly lower comparing to tubes covered with biotextile with 1% SiO_2. In uncovered tubes treated with UV-B, development of larvae stopped and the imago stage was not observed. Composite amber yarn increased the protective capacity of biotextile against UV-B up to 20% (Fig. 4), and addition of 1% SiO_2 nanoparticles in the coating increased the protection of *D. melanogaster* larvae up to 100% and provided full protection.

The wool composite with amber micro particles increased survival of *D. melanogaster* larvae affected by LF-EMF (50 Hz, 450–518 μT) by up to 10%, in comparison with other tested wool specimens (Fig. 4). SiO_2 nanoparticles incorporated in textile improved the protective properties of the textile against LF-EMF (50 Hz, 450–518 μT) (incubation time 2 h), only in the case when textile with 1% concentration of SiO_2 nanoparticles was used. The best protective properties were found in the case of biotextile consisting of wool and composite amber fibres with 1% of SiO_2 nanoparticles.

Growth parameters like total leaf area (Fig. 5), leaf number (Fig. 6) and fresh weight (Fig. 7) of affected by LF-EMF plants as well as possible induction of nucleotide substitutions measured and estimated comparing the results derived

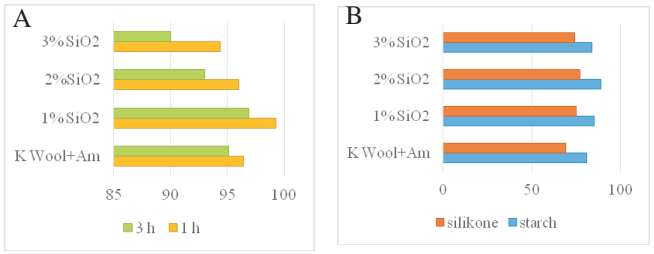


Fig. 3. Relative fluorescence (RF) of gametic cells depending on the type of fabric coverage, containing amber thread and various coatings of SiO_2 nanoparticles (A)m and affected by UV-B for one or three hours and RF of gametic cells, depending on the type of fabric, containing amber thread and various coatings of SiO_2 nanoparticles in composite with silicone and starch (B).

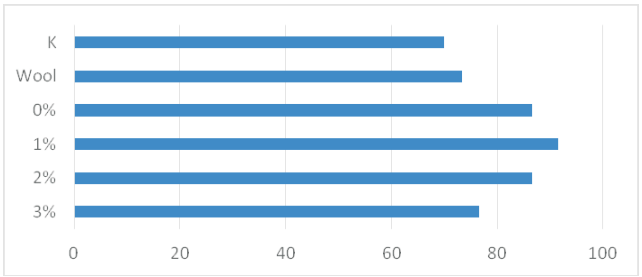


Fig. 4. Survival of *D. melanogaster* imago (%) depending on the SiO_2 concentration and incubation time (incubation in 50 Hz 450 μT ELF-EMF for 2 h).

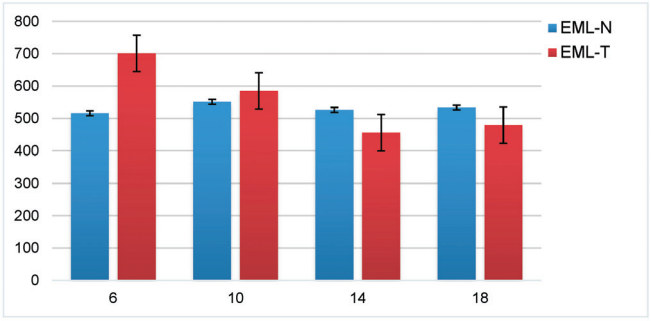


Fig. 5. Total leaf area (mm^2): EML-T – *L. minor* colonies affected by LF-EMF grown inside a Helmholtz coil after 6, 10, 14 and 18 weeks passed from the beginning of the experiment; ML-N – control *L. minor* plants grown at 1.5 m distance from the source of electromagnetic radiation.

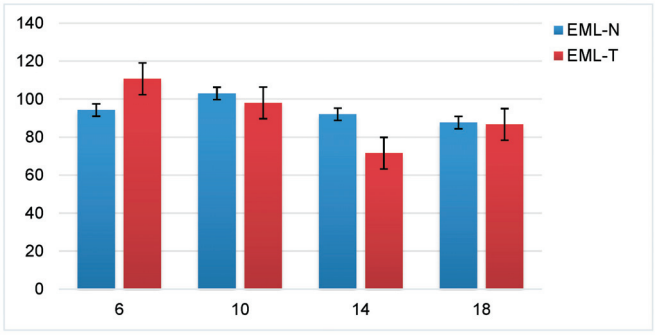


Fig. 6. Total leaf number: EML-T – *L. minor* grown affected by LF-EMF directly grown inside a Helmholtz coil after 6, 10, 14, and 18 weeks from the beginning of the experiment; EML-N – control *L. minor* plants grown at 1.5 m distance from the source of electromagnetic radiation.

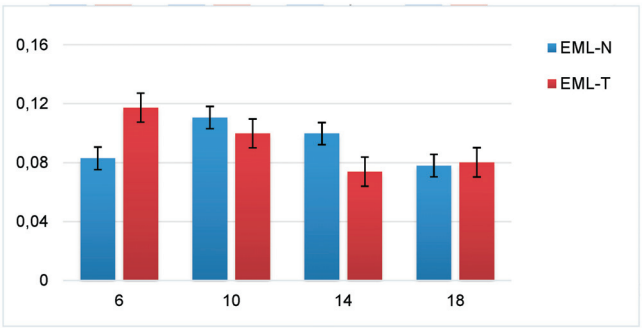


Fig. 7. Fresh plant weight (g): EML-T – *L. minor* colonies affected by LF-EMF directly grown inside a Helmholtz coil after 6, 10, 14 and 18 weeks from the beginning of the experiment; EML-N – control *L. minor* plants grown at 1.5 m distance from the source of electromagnetic radiation.

	9150	9151	9152	9153	9154	9155	9156	9157	9158	9159	9160	9161	9162	9164	9165	9166	9167	9168	9169	9170	9171	9172	9173	9174	9175	9176	9180	9994	10015	10027	10028	10029	10030	10031	10034	10035	10036	10037	10038
	1	2	3	4	5	6	7	8	9	10	11	12	13	15	16	17	18	19	20	21	22	23	24	25	26	27	31	845	866	878	879	880	881	882	885	886	887	888	889
Gpx6L sta2	C	A	T	T	T	T	T	G	G	G	G	T	T	G	G	G	G	T	T	C	A	T	G	G	A	A	A	T	T	G	G	T	C	G	A	T	C	A
Gpx6L SR2	-	-	-	-	-	-	-	-	-	.	.	C	.	.	.	.	A	.	.	C	A	-	-	-	-	G	T	T	A	-	-	-	-	-	-	-	-	-	-
18K1	-	-	-	-	-	-	-	.	.	.	.	.	.	.	T	.	.	A	G	.	G	C	A	A	C	G	T	T	A	.	.	T	.	.	.	.	.	.	.
18EMF1	-	T	A	A	A	A	.	G	.	.	A	.	.	.	.	A	.	A	G	C	A	-	-	-	-	G	T	T	A	.	.	T	C	.	.	.	C	.	.
18K2	.	.	A	.	.	.	.	-	-	.	.	.	.	.	.	A	.	.	C	A	-	-	-	-	-	G	T	T	A	G	-	-	.	T	.	.	.	T	C
18EMF2	-	-	-	-	-	-	-	-	-	-	-	.	C	A	T	.	.	.	.	.	G	.	G	.	C	G	T	T	A	G	T	T	.	.	A	G	A	.	.
18K3	G	G	C	A	.	A	A	.	.	.	A	.	.	.	.	A	.	.	C	A	-	-	-	-	-	G	T	T	A	.	.	T	C	.	.	.	.	.	.
18EMF3	G	G	G	.	.	A	.	.	.	.	.	.	.	.	.	A	.	.	C	A	-	-	-	-	-	G	T	T	A	.	.	T	.	.	.	.	.	.	.
Gpx6L EMF1	-	-	-	-	-	-	-	-	-	-	-	A	C	.	.	A	.	T	C	C	A	-	-	-	-	G	T	T	-	-	-	-	-	-	-	-	-	-	-
Gpx6L EMF2	-	-	-	-	A	G	.	.	.	A	.	.	C	-	-	-	-	-	-	-	-	-	-	-	-	G	T	T	A	-	-	-	-	-	-	-	-	-	-
Gpx6L EMF3	-	-	-	-	-	-	-	-	-	-	-	.	.	.	.	.	A	.	.	C	A	-	-	-	-	G	T	T	-	-	-	-	-	-	-	-	-	-	-

Fig. 8. Nucleotide substitutions in the glutathione peroxidase gene of *L. minor* plants directly affected by electromagnetic field after 18 and 64 weeks by LF EMF (Apx1L 18 k* and Apx1L EMF* specimens) and control (Apx1L 18k* specimens) groups in comparison to reference sequence (Gpx6L sta2 specimen). The blue colour is promoter, black – intron.

from *L. minor* plants grown in Petri plates placed directly in Helmholtz coil (EML-T) or kept on 1.5 m distance (EML-N) from the source of electromagnetic radiation were recorded on 6, 10, 14, and 18 weeks from the after beginning of the experiment. Significant stimulating effect of LF-EMF on growth parameters of *L. minor* was observed up to stimulating on the 10th week from the beginning of the experiment, but starting from the 14th week, suppression of growth parameters of affected by LF-EMF *L. minor* plants was observed supposing the appearance of negative long lasting effects of electromagnetic radiation.

Numerous nucleotide substitutions were detected at *GPx 6* and *Apx1* gene fragments after growing of *L. minor* plants exposed to low frequency electromagnetic radiation (LF-EMF), which were especially apparent after 14 and 18 weeks from the beginning of the experiment (Figs. 8 and 9).

Prolonged (14–18 weeks) exposure to low-frequency electromagnetic radiation affected mostly the non-coding regions of studied *L. minor* genes, including the promoter and first intron in glutathione peroxidase and ascorbate peroxidase genes, but no nucleotide substitutions were observed in catalase gene sequences.

	28320	28326	28328	28335	28339	28350	28361	28376	28438	28450	28451	28499	28505	28531	28538	28712	28828	28937
	73	79	81	88	92	103	114	129	191	203	204	252	258	284	291	465	581	690
Apx1L S2	T	T/A	C/G	C/A	T/A	C/T	G/A	A/T	G	T/C	C	T/A	G/A	A	T/C	C	G	A
Apx1L SR2	.	A/T	G/C	A/C	.	T/C	.	.	.	.	.	A/T	.	.	.	.	.	.
Apx1L 18k1	.	A/T	G/C	A/C	A	.	A/G	T/A	.	C/T	.	.	.	.	C/T	.	C	G
Apx1L 18e1	.	A/T	.	A/C	A	.	A/G	T/A	.	C/T	.	.	.	.	.	.	.	.
Apx1L 18k2	.	A/T	G/C	A/C	A	T/C	.	.	.	C/T	.	.	.	G	.	.	.	.
Apx1L 18e2	.	A/T	G/C	A/C	A	.	.	T/A	.	C/T	A	A/T	.	.	.	.	.	.
Apx1L 18k3	.	A/T	.	A/C	A	T/C	.	.	.	.	.	.	A/G	.	.	.	.	.
Apx1L 18e3	C	A/T	G/C	A/C	A	T/C	A/G	.	T	.	.	A/T	.	.	C/T	T	.	.
Apx1L EMF1	.	A/T	.	A/C	.	T/C	.	.	.	.	.	.	.	.	.	.	.	.
Apx1L EMF2	.	A/T	G/C	A/C	.	.	A/G	.	.	.	.	.	.	.	.	.	.	.
Apx1L EMF3	.	A/T	G/C	A/C	.	.	.	.	.	.	.	.	A/G	.	C/T	.	.	.

Fig. 9. Nucleotide substitutions of ascorbate peroxidase gene in *L. minor* plants directly affected by electromagnetic field after 18 and 64 weeks LF EMF (Apx1L 18 k* and Apx1L EMF* specimens) and control (Apx1L 18k* specimens) groups in comparison to reference sequence (Apx1L S2 specimen). The blue colour is promoter, black – intron, green – exon.

DISCUSSION

With the development and production of innovative biotextiles, there is an increasing need to determine the biosafety of newly invented materials as well as other specific features related to the well-being and health of users. This is especially true when biotextiles with incorporated different nanoparticles are used, the integration of which into the textile can radically change its properties. There is a growing demand for multi-functional nanotextiles, which nowadays are very diverse, providing properties such as UV protection, antimicrobial, sensor, self-cleaning, dust repellence and shielding (protection) from electromagnetic radiation (Ali *et al*., 2023; Nan *et al*., 2023).

Mandatory testing of textile materials are required to introduce new biotextiles, which unfortunately have limited value for determining the biosafety of the materials. To overcome these limitations, we propose EU manufacturers to use the newly developed bioassay, which is based on the application of the most appropriate species as test organisms, and specific methods to collect information regarding protective properties of the new biotextile materials. It is easier and cheaper to test biotextile properties using microorganisms, but their genomes are very different from genomes of eukaryotes, and therefore results obtained on microorganisms not always are transferable to mammals. The assessment of the protective properties of the biotextile by using mammals as test organisms would be more accurate, but this is relatively expensive, time consuming and always requires ethical consideration. Nowadays, *in vitro* cultures of various cells are increasingly being used in biotesting, but it is not always technically possible to use human cell cultures, such as epithelium, in biotextile testing, as their main disadvantage is the need for a constant temperature (37 °C).

Entrepreneurs and engineers, when developing new biotextile materials, usually need to collect knowledge about both the biological activity of the raw materials and the properties of the newly developed biotextile at the final stages of its development. Many testing experiments are needed to gain such knowledge. Therefore, it is very important to develop a bioassay method that is relatively inexpensive, but sufficiently informative and complementary. Close cooperation with biotextile producers and feedback with continuous information is needed for application of new innovative effective biotesting methods that are relatively inexpensive and allow to obtain testing results in a sufficiently short time.

We applied a complex of methods that complement each other, and depending on the purpose of the test, it is possible to supplement the proposed testing system with other methods to obtain more detailed results, such as changes in the function of certain genes. For example, the testing of protective properties of biotextile against UV-B and LF-

EMF radiation using the flow cytometry method to determine changes of cell parameters was shown to be accurate, fast, and relatively inexpensive method. The method is based on determining changes of plant cell naturally fluorescent proteins (Shabrangi *et al*., 2010) up until start of apoptotic processes in cells, which results in decrease of fluorescence (Vigneswaran *et al*., 2009; Martinez *et al*., 2010; Carter *et al*., 2013). The determined parameter (RFU) is representing more than 20 parameters from each cell, and the error of testing does not exceed 3% (Doležel *et al*., 2007; Dimkpa *et al*., 2012). A large number of cells (up to 100,000) are used to test a single sample, which ensures the accuracy of the method and eliminates randomness. The speed of the method is also important: testing of a single series of samples can be performed in 2–3 hours. The use of this method to determine the protection properties of biotextile against electromagnetic fields is based on knowledge that UV-B and LF-EMF radiation are known to be cell stress factors that can affect cellular processes (Karim *et al*., 2012; Peykarestan *et al*., 2012; Franczak *et al*., 2020) including damage to DNA resulting in heritable mutations, and damage leading to disturbance of cell physiological processes.

Previously, gametic cells from *in vitro* culture of cyclamens (C. *persicum*) were used as a model system and results indicating this method as sufficiently sensitive to reveal differences in relative fluorescence after exposure to LF-EMF and UV-B, in comparison to cells of a control groups were obtained. Increase in total relative fluorescence of gametic cells is associated with healthy growth, while decrease in RFU indicates onset of cell apoptosis (cell death) (Grauda *et al*., 2015).

The survival of *D. melanogaster* larvae, and their development to the imago stage was affected by UV-B and LF-EMF radiation, when grown in tubes wrapped in biotextile encompassing varying percentage of nanoparticles. The current test appeared sensitive enough to reveal protective abilities of biotextile samples. The *D. melanogaster* survival test was shown to be a suitable tool that could be included into the panel of the methods suited for biotextile testing.

CONCLUSIONS

The results of the study devoted to evaluating protective properties of different types of biotextile proved that chosen model systems like cultures of the freshwater macrophyte duckweed (*Lemna minor*) line *Sta2* and fruit flies (*Drosophila melanogaster*) were suitable for the study of the influence of electromagnetic field (EMF) radiation. The changes of phenotypic features and growth parameters of test objects affected by LF EMF were revealed.

The results of the sequencing of different fragments of three genes, participating in regulation of cell response to oxidative stress, proved that the impact of the prolonged (14–18 weeks) exposure to LF-EMF on duckweed (*L. minor*) plants experimentally grown in laboratory conditions could be shown on the molecular level, indicating generation of new point mutations. The appearance of new point mutations in relatively short fragments of glutathione peroxidase and ascorbate peroxidase encompassing gene promoter and first intron of both genes should be considered as sensitive and informative genetic markers suitable for testing of the protective properties of newly developed biotextile materials.

It was found that immature gametic (pollen) cell cultures is a highly sensitive model system (plant gametic cell response is comparable to human neutrophil response) to study the influence of EMF radiation with use of flow cytometry method and it shows reliable results in testing different biotextile.

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BIOTESTĒŠANAS SISTĒMAS IZVEIDE INOVATĪVU MULTIFUNKCIONĀLU BIOTEKSTILA ĪPAŠĪBU IZPĒTEI

Pētījuma mērķis bija izveidot testēšanas metožu sistēmu biotekstila materiālu (audumu) specifisko īpašību (tādu kā aizsargspēja pret nelabvēlīgiem vides faktoriem, tai skaitā dažādu frekvenču elektromagnētisko starojumu) noteikšanai bez nepieciešamības veikt eksperimentus ar laboratorijas dzīvniekiem. Par elektromagnētiskā starojuma ietekmes izpētei piemērotu modeļsistēmu tika izvēlēta saldūdens mazo ūdensziedu *Lemna minor* jaunā, laboratorijā izveidotā aksēniskā līnija *Sta2*, augļu mušiņa *Drosophila melanogaster* un augu gametisko šūnu *in vitro* kultūra. Modeļobjektus pārklājot ar dažāda veida biotekstila audumiem, tika konstatētas testa objektu fenotipu un augšanas parametru izmaiņas, kā arī kodola DNS izmaiņas elekromagnētisko (UV-B un LF-EMF (50 Hz, 450 μT) lauku ietekmē un, izmaiņu atšķirības testu laikā,. Testa organismu izmaiņu pētīšanai tika izmantotas fenotipēšanas, mikroskopijas, plūsmas citometrijas un DNS sekvencēšanas metodes. Secināts, ka visi izvēlētie modeļobjekti un metodes ir izmantojamas biotekstila un tā izejvielu biotestēšanā. Konstatēts, ka īpaši perspektīva biotekstila un tā izejvielu biotestēšanā ir nenobriedušu (vienkodola stadijas) gametisko šūnu kultūra, kas ir ļoti jutīga (izmaiņas konstatējamas pēc 2 h inkubācijas) modeļa sistēma un līdz ar to efektīva un lēta, lai veiktu pirmējo biotestēšanu.