Romuald GÓRSKI[1], Hanna DORNA[2*], Agnieszka ROSIŃSKA[2],
Dorota SZOPIŃSKA[2], Filip DAWIDZIAK [1]
and Stanisław WOSIŃSKI[3]

EFFECTS OF ELECTROMAGNETIC FIELDS ON THE QUALITY OF ONION (*Allium cepa* L.) SEEDS

WPŁYW PÓL ELEKTROMAGNETYCZNYCH NA JAKOŚĆ NASION CEBULI (*Allium cepa* L.)

Abstract: The aim of this paper was to establish whether electromagnetic fields (EMF) with a super low frequency (SLF) have a negative effect on onion seed quality. Three sectors were separated on the device emitting electromagnetic fields: „E" – sector emitting electromagnetic radiation with the predominance of the electrical component, „EM" – sector emitting electromagnetic radiation without domination of its components and „M" – sector with a predominance of magnetic component. Seed germination and vigour were evaluated at 20 ^{o}C in darkness. Mycological analysis was performed using a agar plate method. Exposure of seeds to electromagnetic fields did not affect G_{max}. Treated seeds were characterized with significantly lower germination capacity and higher percentage of deformed abnormal seedlings than untreated seeds. Electromagnetic radiation with the predominance of electrical component (E), and electromagnetic radiation with the predominance of magnetic component (M) also significantly decreased the germination energy. The effect of electromagnetic fields on the speed of germination was ambiguous. Seeds treated with the electromagnetic field with predominance of magnetic component (M), and electromagnetic field without domination of its components (EM) germinated significantly less uniformly than control. Generally, exposure of seeds to electromagnetic fields did not influence the incidence of fungi.

Keywords: electromagnetic field, onion, seed germination, vigour, fungi

Introduction

Everyday use of an electrical household equipment and the rapid development of technologies such as the Internet, cellular phone networks, and satellite navigation systems have resulted in an ever-increasing electromagnetic smog, which is hazardous to human health. Nowadays, the level of electric fields in everyday situations is

[1] Department of Entomology and Environmental Protection, Poznań University of Life Sciences, ul. Dąbrowskiego 159, 60-594 Poznań, Poland, +48 618 466 336, email: romuald.gorski@up.poznan.pl

[2] Department of Phytopathology, Seed Science and Technology, Poznań University of Life Sciences, ul. Dąbrowskiego 159, 60-594 Poznań, Poland,+48 618 466 384, email: hanna.dorna@up.poznan.pl

[3] ADR Technology, ul. Żeleńskiego 18, 80-285 Gdańsk, Poland, email: s.wosinski@adrtechnology.eu

* Corresponding author: hanna.dorna@up.poznan.pl

considerably higher than approximately 130 years ago due to the application of electrical technologies. The frequency ranges that are applied to modern electrical technologies that concern human and animal health are in general, Extremely Low Frequency (ELF) 3 Hz – 30 Hz, Super Low Frequency (SLF) 30 Hz – 300 Hz (power lines, household electrical appliances, computers, etc) and Ultra High Frequency (UHF) 300 MHz – 3 GHz (digital television, mobile phones, routers, etc). It should be noted that long-term exposure to electromagnetic field (EMF), even of minor strength, may influence people's well-being [1–9].

Animal studies proved that electromagnetic fields might present genotoxic effects and lead to significantly increased DNA damage in rats after exposure to 60 Hz, 10 μT magnetic fields for 24 or 48 hours [10]. In humans, it has been also reported that 50 Hz EMF elevates the frequencies of sister chromatid exchanges in lymphocytes [11]. Interestingly, DNA damage in human cells exposed to SLF electromagnetic fields was counteracted by the addition of antioxidants, suggesting that SLF can indirectly affect DNA integrity, possibly via changes in radical homeostasis [12].

In 2002, an International Agency for Research on Cancer (IARC) published a monograph on the evaluation of carcinogenic risks of static and low frequency electric and magnetic fields to humans [13]. Low frequency electromagnetic fields were classified by WHO into group 2B, meaning that they are "possibly carcinogenic to human". Furthermore, in 2011, electromagnetic fields of radio frequencies were also classified as „possibly carcinogenic to humans", as contributing to the development of brain glioma [14]. Epidemiological studies have shown an association with an increased leukemia risk for children exposed to super low frequency electromagnetic field (SLF), as well as increased breast and brain cancer risk [15–17]. SLF electromagnetic fields can also promote the development of cancer through non-genotoxic mechanisms such as stimulation of cell proliferation and inhibition of apoptosis. What is more, an increase in cell proliferation markers in rat mammary glands has been reported, as well as inhibition of UV radiation-induced apoptosis in mouse skin [18,19].

The association of different levels of EMF emitted by devices such as mobile phones, laptop computers, microwave ovens or Wi-Fi with male fertility has been also reported. Male infertility has become a common public health problem and is thought to be caused by several factors, including the harmful effects of the electromagnetic field emitted by various electrical devices on the human body [20–25].

The aim of this paper was to establish whether electromagnetic fields (EMF) with a super low frequency (SLF) can also have a negative effect on plants. In the study, the effect of electromagnetic fields on germination and vigour of onion seeds and their infestation with fungi was determined.

Material and methods

Material

Onion (*Allium cepa* L.) seeds cv. Stuttgater Reisen were used in the experiment. They were subjected to electromagnetic fields emitted by a specially designed device (EM emitter) as shown in Figure 1.

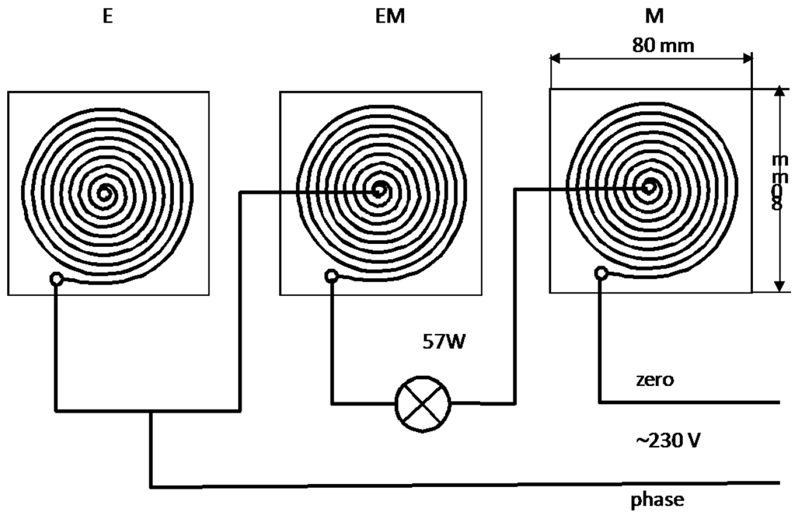

Fig. 1. Schematic diagram of the equipment used in the application of electromagnetic fields (EMF): *E* – electromagnetic field with the predominance of the electrical component, *M* – electromagnetic field with the predominance of magnetic component, *EM* – electromagnetic field without domination of its components

The device emitting electromagnetic fields is composed of 3 spiral coils, constructed using a glass-epoxy laminate coated with copper (20 μm), which is used for printed circuits. The coils are placed directly behind the upper wall of the housing which is made of plastic and connected by electrical wires. The wiring diagram is shown in Figure 1, the electrical wires are separated from the coils at a distance of about 5 cm. The distance between the coils is 15 cm. The electricity receiver is a 57 W halogen bulb, which was placed in the lamp outside the casing of the device, within a few meters distance to minimize the influence of thermal radiation of the bulb on the tested object. A black shade on the lamp protected against light exiting to the outside and its possible influence on the experiment's objects.

Three sectors were separated on the device. Thus different types of electromagnetic fields were produced. They were marked as „E" – a sector emitting electromagnetic radiation with the predominance of the electrical component, „EM" – a sector emitting electromagnetic radiation without domination of its components and „M" – a sector with the predominance of magnetic component. The method for creating the predominance of electric (*E*) and magnetic field (*M*) is shown in the diagram (Figure 1). When the bulb is lit, between the bulb and zero (neutral) there is the predominance of magnetic field (*M*), between the lit bulb and the phase (live) there is electric and magnetic, where the antenna is connected only to the phase (live) then there is a predominance of electric field (*E*).

Petri dishes with seeds were placed individually in the mentioned sectors, emitting differential electromagnetic fields. Specific values of field components generated by the device are shown in Tables 1.

Table 1

Values of the intensity of electromagnetic fields measured 9 mm above the field generating device. Measurements were made using Maschek 3030B.
The field generating device was loaded with 57 W receiver

Components	Sector E	Sector EM	Sector M
SE [V · m^{-1}]	2140	1667	320
SM [μT]	0.36	5.51	5.57

SE – electrical component; *SM* – magnetic component; Sector E – a sector emitting electromagnetic field with the predominance of the electrical component; Sector EM – a sector emitting electromagnetic field without domination of its components; Sector M – a sector emitting electromagnetic field with the predominance of magnetic component.

Methods

Seed germination was tested according to ISTA Rules [26], in each treatment 200 seeds (four 50 seed replicates) were evaluated. Seeds were placed in Petri dishes (50 seeds per dish), on 6 layers of blotter paper moistened with distilled water. Petri dishes with seeds were incubated at 20 ^{o}C in darkness, directly on the top of the device emitting electromagnetic fields. Germination energy was evaluated after 6 days of incubation, whereas germination capacity, the percentages of abnormal diseased seedlings, abnormal deformed seedlings, fresh seeds and dead seeds were determined after 12 days. Additionally the percentage of germinating seeds (G_{max}) was calculated on the base of seed vigour test.

Seed vigour evaluation was also conducted in four 50 seed replicates (200 seeds for each treatment). The test conditions were the same like in the seed germination test. Germinating seeds were counted daily and removed from the plate, until no new germs appeared. Seeds with the radicle at least 1 mm long were considered as germinating. Based on obtained results the speed and uniformity of germination i.e. T_1 – time to 1 % of G_{max}, T_{25} – time to 25 % of G_{max}, T_{90} – time to 90 % of G_{max}, *MGT* – mean germination time, U_{90-10} – time between 10 and 90 % of G_{max} were calculated according to Joosen et al. [27].

Mycological analysis was performed using an agar plate method. In each treatment 200 seeds (four replicates of 50 seeds) were evaluated. They were placed in 9 cm diameter Petri dishes on the surface of potato dextrose agar (PDA), 10 seeds per dish. Streptomycine at concentration of 100 ppm was added to the medium to prevent bacteria occurrence. The seeds were incubated for ten days at 20 ^{o}C under 12 h alternating cycles of NUV (Near Ultraviolet) light and darkness. During incubation Petri dishes with seeds were placed on the top of the device emitting electromagnetic fields. Fungi were identified on the base of the appearance of their colonies and sporulation [28–30]. The percentages of seeds infested with individual fungi were determined.

The results obtained were evaluated by one-way analysis of variance followed by Duncan's multiple range test, at a level α = 0.05. Parameters characterising seed vigour were calculated using Germinator software [27].

Results

Untreated seeds were characterized by high total number of germinating seeds (G_{max}) and germination capacity, 91.5 and 93.0 % respectively. *Alternaria alternata* (Fr.) Keissler, *Aureobasidium* spp. and *Penicillium* spp. prevailed on tested seeds. Moreover, other fungi i.a. *Cladosporium* spp., *Epicoccum nigrum* Link. and *Fusarium* spp. were detected (Table 2, 4).

Exposure to electromagnetic radiation with the predominance of the electrical component (*E*), electromagnetic field with the predominance of magnetic component (*M*), and electromagnetic radiation without domination of its components (*EM*), resulted in a decrease in seed germination energy and germination capacity compared to control. All treatments increased the percentage of abnormal deformed seedlings. Exposure of seeds to electromagnetic radiation did not affect the percentages of abnormal diseased seedlings, fresh seeds and dead seeds (Table 2).

Table 2

Effects of electromagnetic fields on seed germination

Treat-ments	G_{max} [%]	Germination energy [%]	Germination capacity [%]	Abnormal diseased seedlings [%]	Abnormal deformed seedlings [%]	Fresh seeds [%]	Dead seeds [%]
C	91.5 a	89.5 b	93.0 c	3.5 a	0.0 a	0.0 a	3.5 ab
E	91.5 a	80.5 a	84.5 a	6.5 a	3.5 b	1.0 a	4.5 b
EM	88.5 a	85.5 ab	87.5 ab	5.5 a	4.5 b	1.5 a	1.0 a
M	87.5 a	82.5 a	87.5 ab	4.5 a	4.5 b	0.0 a	3.5 ab

Means in columns followed by the same letters are not significantly different at $\alpha = 0.05$ level according to Duncan's test.

C – untreated seeds; *E* – electromagnetic radiation with the predominance of the electrical component; *EM* – electromagnetic field without domination of its components; *M* – electromagnetic field with the predominance of magnetic component; G_{max} – the percentage of germinating seeds.

Exposure of seeds to electromagnetic fields significantly reduced the value of T_1 parameter. Seeds subjected to electromagnetic field with the predominance of electrical component (*E*), and electromagnetic field without domination of its components (*EM*), were characterized also with a lower value of T_{25} parameter compared to control. Only treatment with electromagnetic field with the predominance of electrical component (*E*) did not influence negatively T_{90}, other treatments significantly deteriorated that parameter. Acceleration of MGT was observed only after seed treatment with electromagnetic field with the predominance of electrical component (*E*). Seeds exposed to electromagnetic fields with the predominance of magnetic component (*M*) and without domination of its components (*EM*) germinated significantly less uniformly than control and seeds treated with electromagnetic field with the predominance of electrical component (*E*) (Table 3).

Table 3

Effects of electromagnetic fields on seed vigour

Treat-ments	Speed of germination [days]				Uniformity of germination [days]
	T_1	T_{25}	T_{90}	*MGT*	U_{90-10}
C	1.37 c	2.02 c	3.24 a	2.46 b	1.48 a
E	0.83 a	1.51 a	2.97 a	2.03 a	1.75 a
EM	0.69 a	1.68 b	3.94 b	2.48 b	2.69 c
M	1.07 b	1.91 c	3.73 b	2.56 b	2.17 b

Means in columns followed by the same letters are not significantly different at $\alpha = 0.05$ level according to Duncan's test.

T_1 – time to 1 % of G_{max}; T_{25} – time to 25 % of G_{max}; T_{90} – time to 90 % of G_{max}; *MGT* – mean germination time; U_{90-10} – time between 10 and 90 % of G_{max}.

For other explanations see Table 2.

Exposure of seeds to electromagnetic radiation generally did not influence the incidence of fungi. Seed infestation with *Penicillium* spp. decreased only after exposure of seeds to field without domination of its components (*EM*), compared to control. (Table 4).

Table 4

Effects of electromagnetic fields on the seed infestation with fungi (the percentage of infested seeds)

Treat-ments	*Alternaria alternata*	*Aureobasidium* sp.	*Cladosporium* spp.	*Epicoccum nigrum*	*Fusarium* spp.	*Penicillium* spp.
C	17.0 a	9.0 a	3.0 a	0.5 a	3.0 a	15.0 bc
E	24.0 a	6.0 a	1.5 a	1.5 a	1.0 a	8.0 ab
EM	20.5 a	6.5 a	0.0 a	2.0 a	0.0 a	5.5 a
M	20.5 a	6.5 a	0.5 a	0.0 a	1.5 a	18.0 c

Means in columns followed by the same letters are not significantly different at $\alpha = 0.05$ level according to Duncan's test.

For other explanations see Table 2.

Discussion

It has been found in the present experiment that exposure of onion seeds to electromagnetic radiation negatively influenced seed germination energy and germination capacity compared to untreated seeds. Electromagnetic radiation with the predominance of magnetic component (*M*) significantly decreased the germination energy and germination capacity, by 7.0 and 5.5 % respectively, compared with untreated seeds.

Significant negative changes in plants after exposure to electromagnetic fields were also observed in studies carried out by other authors. The influence of electromagnetic field depends on natural factors such as: the plant species and plant variety, as well as a large number of physical factors such as: exposure time, induction and frequency of the field. According to Grabowska et al. [31] onion seeds of cv. Sochaczewska, exposed to a 50 Hz, 100 mT electromagnetic field for 30 s, were characterized by slower germination and also worse quality in relation to control. Moreover, plants grown from exposed seeds showed a lower ability to survive. In our experiment the effect of low frequency electromagnetic fields on the speed of onion seeds germination was ambiguous. Initially, treated seeds germinated faster, significantly lower values of T_1 and T_{25} parameters were observed compared to the control. On the other hand, time to germinate 90 % of seeds of total number of germinating seeds (T_{90}) after seed exposure to electromagnetic field with the predominace of magnetic componet (*M*) and electromagnetic field without domination of its componets (*EM*) was longer. In addition, seeds treated with these electromagnetic fields germinated less uniformly. Dorna et al. [32] reported that carrot seeds of cv. Perfekcja exposed to permanent magnetic field germinated faster than untreated seeds, whereas in case of cv. Nantejska a delay in seed germination was noted.

Grabowska et al. [31] indicated that exposure of radish seeds of cv. Agata to electromagnetic field (50 Hz, 60 mT) for 4 and 60 s reduced germination capacity and crop yield. No changes were found for the cultivar Murzynek. In case of spring wheat cv. Koksa and Tybalt, after exposure of seeds to electromagnetic field (50 Hz, 30 mT) for 8 or 15 s the reduction in protein and gluten content has been found. Balakhnina et al. [33] did not observe the effect of exposure of wheat seeds to electromagnetic field strength of 30 mT and 50 Hz frequency for 30 s on their germination and seedling growth processes.

Das and Bhattacharya [34] revealed that high electric field had a negative effect on the growth of gram (*Cicer arietinum* L.) roots. Authors reported that the application of electric field of 150 $kV \cdot m^{-1}$ on gram seeds for 20 min decreased the root length by 14 % compared to control. With the increase of electric field strength the root growth was reduced further. Shrabangi et al. [35] showed that fresh and dry weight of shoot and root of maize grown from seeds exposed to extremely low electromagnetic fields were significantly reduced compared to the control plants. According to authors that phenomenon may be due to lower rate of protein synthesis in pretreated plants. In our experiment the significantly higher percentage of abnormal deformed seedlings was observed after seed treatment with electromagnetic fields. Gemici et al. [36] reported that high voltage lines (0.1–10 mG and 50–60 Hz) had negative effects on the growth and development of the walnut and cherry trees. Leaves were thinner and leaf mesophyll was more densely packed than in case of control trees. Authors observed also the increase in abscisic acid (ABA) content and the decrease in gibberelic acid (GA_3), chlorophyll a and b contents in plants leaves exposed to electromagnetic fields of high voltage transmission lines compared to control trees. Biketi et al. [37] also found that the level of chlorophyll a was lower in plants, which were exposed to 50 Hz magnetic field with the induction of 0.5–3 mT. Hasan et al. [38] showed that magnetic field had a negative influence on the maize growth. Authors conducted a simulation of electromagnetic field of 400 kV high voltage transmission line in laboratory. After exposure to electromagnetic field they observed a reduction in plant growth. The decrease in plant growth depended on the strength of the magnetic field. It has been found that the impact of electromagnetic radiation of a certain intensity can cause genetic mutations in plants [39].

Studies conducted by some authors showed that stimulation by permanent magnetic or the electromagnetic field with appropriately selected intensity, frequency and magnetic induction can also cause positive changes in biochemical and physiological processes in seeds and plants, and can have a positive effect on the plant growth, development and yield. According to Dannehl [40] magnetic and electric fields are the physical factors that improve seed quality. Positive impacts include better seed germination, seedling growth and higher yields. Moreover seedlings obtained from treated seeds are more resistant to unfavourable environmental conditions [41]. Rochalska et al. [42] reported that pre-sowing stimulation with 16 Hz alternating magnetic field with induction 5 mT had a positive influence on wheat seed germination. Jedlicka et al. [43] found that 50 Hz electromagnetic field with the induction of 20, 40 and 60 mT and the exposure time of 20 minutes a day, had a stimulatory effect on seed germination, plant growth and size of tomato fruits. Zardzewiały et al. [44] found that sugar beet seeds exposed to electromagnetic field induction of 40 mT and 50 Hz frequency for 60 s germinated significantly faster than control seeds. Both components of electromagnetic field, electrical and magnetic, may contribute to accelerate water absorption by seeds [45, 46]. According to Podlesna et al. [47] seeds stimulated by electromagnetic fields imbibe and germinate faster than untreated ones because of more advanced enzyme activity. Grzesik et al. [48] showed that the exposure of apple seeds cv. Ligol for 1 h to pulsed radio frequency PRF (25 V, 4 Hz, 20 ms) during their stratification increased the percentage and dynamics of seed germination as well as dynamics of seedling growth. Pietruszewski at al. [49] reported that the mechanism of influence of electromagnetic fields on plants is still unknown and positive effect on the percentage of seed germination, germination rate and the growth speed is temporary and impermanent. Effects of electromagnetic fields on seed germination depend, among others, on magnetic field induction. Kornarzyński and Pietruszewski [50] treated wheat seeds with electromagnetic field (50 Hz) with different doses of magnetic induction (1.5, 5, 15, 30, 60, 90 mT) for one hour. Depending on the magnetic field induction, positive (1.5 and 5 mT) or negative (15, 30, 60, 90 mT) effects were found on the initial germination phase. Racuciu and Creanga [51] observed an acceleration of the plant growth and root development as well as stimulation of protein synthesis after *Cucurbita pepo* seeds' exposure to low frequency electromagnetic field.

High infestation with fungi may negatively influence germination capacity. According to Afzal et al. [52] static or alternating magnetic fields can reduce negative effects of fungal infection. Janas at al. [53] reported that pulsed radio frequency (PRF) seed treatments (for 30, 60 or 120 min, at a voltage of 5 or 25 V, 2 or 4 Hz, with a pulse duration of 10 or 20 ms) significantly reduced the incidence of seed-borne fungi in beetroot, lettuce and garden dill and improved the dynamics of seed germination, plant emergence and growth. However, in the present experiment it has been found that the exposure of seeds to electromagnetic radiation generally did not influence the incidence of fungi. Onion seeds were infested with fungi to a low extent, mainly with *Alternaria alternata* (Fr.) Keissler, *Aureobasidium* spp. and *Penicillium* spp. Only seeds exposed to electromagnetic field without domination of its components (*EM*), were less infested with *Penicillium* spp. than control seeds. The lack of differences in the number of abnormal diseased seedlings showed that seed colonization by fungi was not a reason for the reduction of germination.

Conclusion

1. Treated seeds were characterized by significantly lower germination capacity and a higher percentage of abnormal deformed seedlings than untreated seeds. Electromagnetic radiation with the predominance of electrical component (*E*) and electromagnetic radiation with the predominance of magnetic component (*M*) also significantly decreased the germination energy. Exposure of seeds to electromagnetic fields did not affect G_{max}.
2. The effect of electromagnetic fields on the speed of germination was ambiguous. Seeds treated with electromagnetic field with the predominance of magnetic component (*M*) and electromagnetic field without domination of its components (*EM*) germinated significantly less uniformly than control seeds.
3. Generally, exposure of seeds to electromagnetic radiation did not influence the incidence of fungi.

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WPŁYW PÓL ELEKTROMAGNETYCZNYCH NA JAKOŚĆ NASION CEBULI (*Allium cepa* L.)

[1] Katedra Entomologii i Ochrony Środowiska, Uniwersytet Przyrodniczy w Poznaniu, Poznań
[2] Katedra Fitopatologii i Nasiennictwa, Uniwersytet Przyrodniczy w Poznaniu, Poznań
[3] ADR Technology, Gdańsk

Abstrakt: Celem prowadzonych badań było ustalenie, czy pola elektromagnetyczne (EMF) o super niskiej częstotliwości (SLF) mają negatywny wpływ na jakość nasion cebuli. Na urządzeniu emitującym pola elektromagnetyczne wyodrębniono trzy sektory: „E" – sektor emitujący promieniowanie elektromagnetyczne z przewagą składowej elektrycznej, „EM" – sektor emitujący promieniowanie elektromagnetyczne bez dominacji jego składowych oraz „M" – sektor z przewagą składowej magnetycznej. Kiełkowanie i wigor nasion oceniono w temperaturze 20 °C w ciemności. Analizę mikologiczną przeprowadzono za pomocą testu agarowego. Poddanie nasion działaniu pól elektromagnetycznych nie wpłynęło na wartość G_{max}. Traktowane nasiona charakteryzowały się znacznie niższą zdolnością kiełkowania i wyższym odsetkiem siewek anormalnych zniekształconych niż nasiona nietraktowane. Promieniowanie elektromagnetyczne z przewagą składowej elektrycznej (*E*) oraz promieniowanie elektromagnetyczne z przewagą składowej magnetycznej (*M*) istotnie zmniejszyło także energię kiełkowania. Wpływ pól elektromagnetycznych na szybkość kiełkowania był niejednoznaczny. Nasiona poddane działaniu pola elektromagnetycznego z przewagą składowej magnetycznej (*M*) i pola elektromagnetycznego bez dominacji jego składowych (*EM*) kiełkowały istotnie mniej wyrównanie niż nasiona nietraktowane. Zasadniczo, poddanie nasion działaniu pól elektromagnetycznych nie miało wpływu na występowanie na nich grzybów.

Słowa kluczowe: pole elektromagnetyczne, cebula, kiełkowanie nasion, wigor, grzyby