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EFFECTS OF A PERMANENT MAGNETIC FIELD TOGETHER WITH THE SHIELDING OF AN ALTERNATING ELECTRIC FIELD ON CARROT SEED VIGOUR AND GERMINATION

WPŁYW STAŁEGO POLA MAGNETYCZNEGO Z RÓWNOCZESNYM EKRANOWANIEM PRZEMIENNEGO POLA ELEKTRYCZNEGO NA WIGOR I KIEŁKOWANIE NASION MARCHWI

Abstract: The purpose of the study was to determine the effect of a permanent magnetic field together with the shielding of an alternating electric field on seed vigour and germination of carrot cultivars 'Perfekcja' and 'Nantejska'. An ADR-4 (**A**dvanced **D**ielectric **R**adiation Trap) apparatus constructed of the porous ceramic with embedded water in a crystalline form was used in the experiment. This material has a very strong shielding effect on alternating electric fields in the low frequency range from 10^{-2} Hz to 10^{6} Hz. The maximum dielectric loss is reached at about 50 Hz. Ten ferrobaryte permanent magnets were placed on the dielectric in a well-defined configuration. During germination seeds were exposed to the action of the ADR-4 apparatus, the ceramic material without magnets and magnets alone. Seed vigour and germination were evaluated at 20°C in the dark. Seed vigour was determined by means of the rate and uniformity of seed germination. The percentage of germinating seeds, germination capacity, the percentages of diseased and deformed seedlings and dead seeds were evaluated. ADR-4 did not affect seed vigour, but improved the germination capacity of seeds and decreased the percentage of diseased seedlings. In cv. 'Nantejska' a lower percentage of dead seeds was observed compared with the control. The ceramic dielectric without magnets accelerated germination of 'Perfekcja' seeds at the initial phase, improved germination capacity and decreased the number of dead seeds in cv. 'Nantejska'. 'Perfekcja' seeds exposed to magnetic field alone germinated faster than untreated seeds, whereas in case of cv. 'Nantejska' a delay in seed germination was found. In cv. 'Perfekcja' a lower percentage of diseased seedlings and in cv. 'Nantejska' an improved germination capacity were observed.

Keywords: stationary magnetic field, alternating electric field, carrot, seed vigour, germination

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Organic crop production demands even higher quality seeds than conventional farming. Preventive and control measures using chemicals are prohibited and competition with weeds requires high vigour propagation material. Moreover, for organic farmers, seed health is very important. Hence, physical methods of improving seed quality have been the subject of intense research. First successful attempts to improve quality of seeds by their exposure to magnetic or electromagnetic fields were carried out in the 1930s. At present research concerning this area is still being continued, but with a better understanding of the mechanism of action of magnetic fields on plants. Enhancement of seed vigour and germination of different species by treating seeds with magnetic or electromagnetic fields has been confirmed by many scientists [1-6]. Vashisth and Nagarajan [7] reported a 46÷71% increase in chickpea seed vigour, a 58÷90% improvement in seedling root length and a 25÷47% increase in seedling dry weight. However, not all results are so spectacular. They depend to a large extent on the conditions of experiments.

The purpose of the study was to determine the effect of a permanent magnetic field together with the shielding of an alternating electric field on seed vigour and germination in carrot cultivars 'Perfekcja' and 'Nantejska'.

Methods and materials

In the experiment a ADR-4 plate (**A**dvanced **D**ielectric **R**adiation Trap) constructed of a porous ceramic with embedded water in a crystalline form and ten permanent magnets was used [8]. Magnets made of ferrobaryte of magnetic field induction ca 40 mT were placed on the ceramic in a well-defined configuration. The ceramic dielectric shows a strong, characteristic, low-frequency absorption of an electric component of the electromagnetic wave in the frequency range from 10^{-2} Hz to 10^{6} Hz at room temperature. The ceramic exhibits a broad low-frequency dielectric anomaly around the temperature of 273 K. The size and shape distribution of pores in the ceramic element is responsible for a broadening of the dielectric anomaly related to freezing of the confined water. The effect is a strong absorption of an electric field from the surrounding medium. The maximum dielectric loss is reached at about 50 Hz (Figures 1-3).

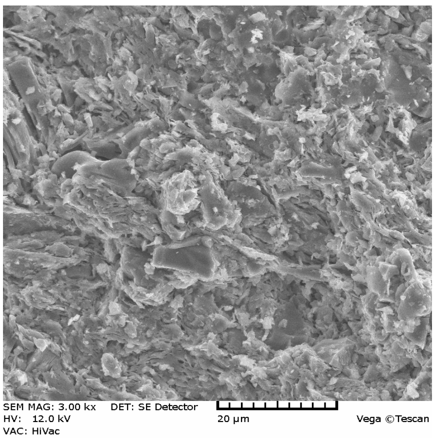

Fig. 1. Topography of surface of ceramic fracture at a compressing pressure of 20 MPa and a temperature of 1100ºC shown on a SEM image

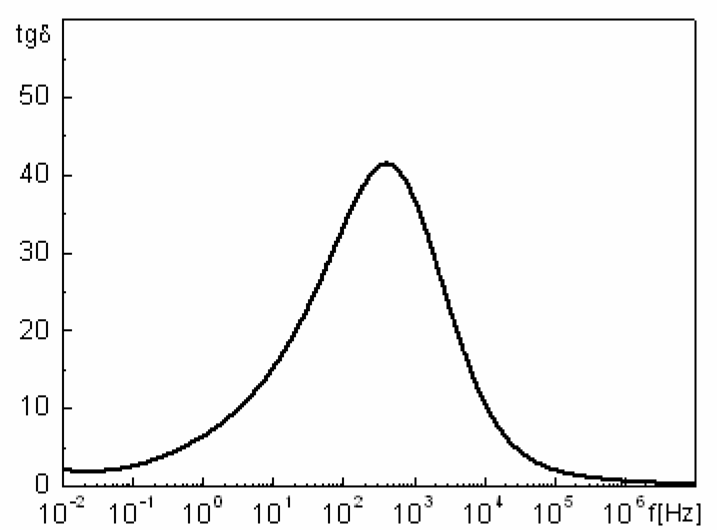

Fig. 2. Results of electric testing dielectric loss. Measurement taken with an Impedance Analyzer HP4192A, at 16ºC and relative humidity of 65%

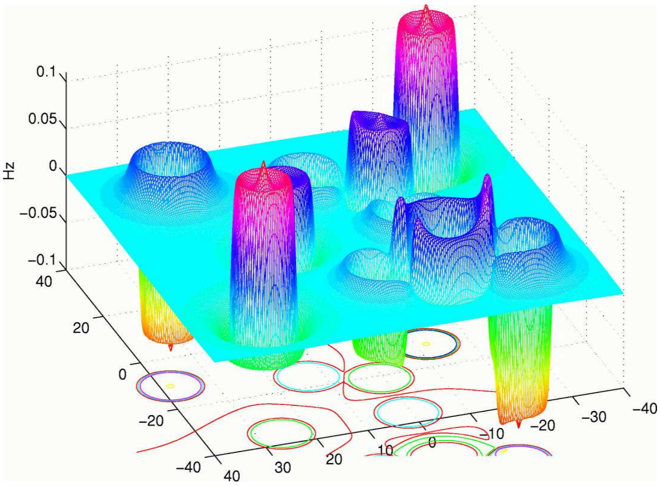

Fig. 3. Spatial distribution of [Hz] magnetic field intensity over ADR-4™

The effect of the ADR-4 plate, the ceramic dielectric without magnets and magnetic elements without the ceramic dielectric on vigour and germination of carrot 'Perfekcja' and 'Nantejska' seeds was examined in the experiment.

Seed vigour was evaluated at 20°C in the dark on 8 replicates of 50 seeds from each treatment. Seeds were placed in 9 cm diameter Petri dishes containing 6 layers of blotting paper moistened with distilled water. The Petri dishes with seeds were placed directly on the top of ADR-4 plates, ceramic dielectrics or on the top of plates which contained only magnetic elements. Germinating seeds, i.e. showing a visible root protrusion through the pericarp, were counted daily until no new germs appeared and they were removed from Petri dishes. Values of T_{10} (time to 10% of the total number of germinating seeds) and T_{50} (time to 50% of the total number of germinating seeds) were calculated. These parameters describe the rate of seed germination. The uniformity of seed germination was evaluated by means of U_{75-25} (time between 75 and 25% of the total number of germinating seeds). Untreated seeds constituted the control.

Germination tests were conducted on 8 replicates of 50 seeds from each treatment. Seeds were incubated under the same conditions as described above. After 14 days of incubation, the percentages of normal seedlings (germination capacity), diseased seedlings, deformed seedlings and dead seeds were evaluated according to the ISTA Rules [9]. Moreover, G_{max} (the percentage of germinating seeds) was determined.

The SeedCalculator version 2.1 software [10] was applied to calculate T_{10}, T_{50}, U_{75-25} and G_{max} parameters. All vigour and germination results were evaluated by means of variance analysis followed by the Duncan test.

Results

ADR-4 did not affect seed vigour, but improved germination capacity of seeds and decreased the percentage of diseased seedlings in both cultivars. In cv. ‘Nantejska’ a lower percentage of dead seeds was observed after their exposure to the action of ADR-4 compared with the control (Tables 1-3).

Table 1

Effects of treatment on seed vigour

Seed treatment	‘Perfekcja’			‘Nantejska’		
	T_{10} [days]	**T_{50} [days]**	**U_{75-25} [days]**	**T_{10} [days]**	**T_{50} [days]**	**U_{75-25} [days]**
Untreated seeds	2.35 a	3.01 a	0.83 a	2.27 ab	3.11 b	0.99 a
ADR-4	2.29 ab	2.98 ab	0.86 a	2.24 ab	3.07 b	1.07 a
M1	2.18 b	2.90 ab	0.93 a	2.21 b	3.08 b	1.08 a
M2	2.15 b	2.86 b	0.91 a	2.42 a	3.26 a	1.02 a

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

ADR-4 - **A**dvanced **D**ielectric **R**adiation Trap.
M1 - ceramic dielectric without magnetic elements.
M2 - ten magnets in the same configuration as in ADR-4 without ceramic dielectric.
T_{10} - time to 10% of the total number of germinating seeds.
T_{50} - time to 50% of the total number of germinating seeds.
U_{75-25} - time between 75 and 25% of the total number of germinating seeds.

Ceramic dielectric without magnets increased germination rate of ‘Perfekcja’ seeds at the initial phase. The T_{10} value was significantly lower than that for untreated seeds. In cv. ‘Nantejska’ this treatment improved seed germination capacity and decreased the percentage of dead seeds (Tables 1-3).

Magnets without the ceramic dielectric accelerated germination of ‘Perfekcja’ seeds. The T_{10} and T_{50} values were significantly lower than those for untreated seeds. On the other hand, this treatment had an adverse effect on seed germination rate in cv. ‘Nantejska’. The T_{50} value was significantly higher than that in the control (Table 1). Exposure to magnetic field improved germination capacity of 'Nantejska' seeds and decreased the percentage of dead seeds. In cv. 'Perfekcja' a lower percentage of diseased seedlings and higher percentage of deformed seedlings were observed after this treatment compared with the control (Tables 2 and 3).

Table 2

Effects of treatment on germination of 'Perfekcja' seeds

Seed treatment	**G_{max} [%]**	**Germination capacity [%]**	**Diseased seedlings [%]**	**Deformed seedlings [%]**	**Dead seeds [%]**
Untreated seeds	93.0 a	56.5 b	35.3 a	1.3 b	7.0 a
ADR-4	93.0 a	64.3 a	26.5 bc	2.8 ab	6.5 a
M1	91.8 a	56.5 b	31.5 ab	2.8 ab	9.3 a
M2	91.0 a	62.3 ab	24.0 c	4.8 a	9.0 a

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

ADR-4 - **A**dvanced **D**ielectric **R**adiation Trap.
M1 - ceramic dielectric without magnetic elements.
M2 - ten magnets in the same configuration as in ADR-4 without ceramic dielectric.
G_{max} - the percentage of germinating seeds.

Table 3

Effects of treatment on germination of 'Nantejska' seeds

Seed treatment	**G_{max} [%]**	**Germination capacity [%]**	**Diseased seedlings [%]**	**Deformed seedlings [%]**	**Dead seeds [%]**
Untreated seeds	91.3 a	50.5 b	34.5 a	0	15.0 a
ADR-4	90.8 a	67.8 a	21.5 b	0	9.3 bc
M1	90.0 a	69.0 a	23.3 a	0	6.3 bc
M2	88.8 a	64.0 a	28.0 a	0	7.3 bc

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

ADR-4 - **A**dvanced **D**ielectric **R**adiation Trap.
M1 - ceramic dielectric without magnetic elements.
M2 - ten magnets in the same configuration as in ADR-4 without ceramic dielectric.
G_{max} - the percentage of germinating seeds.

None of the treatments applied influenced the uniformity of germination or the percentage of germinating seeds (Tables 1-3).

Discussion

Both seed samples used in the study were of poor quality. Germination capacity of untreated seeds was low and a high percentage of diseased seedlings was observed. Seed health evaluation showed that seeds were infected to a large extent by two pathogenic fungi *Alternaria dauci* (J.G. Kühn) J.W. Groves & Skolko and *A. radicina* Meier, Drechsler & E.D. Eddy, which cause seedling damping-off (unpublished data).

This study showed that exposure of seeds from both samples to ADR-4 plates or the ceramic dielectric in general did not affect their vigour. The influence of magnets alone on seed vigour was differentiated. Magnetic field accelerated seed germination in cv.

'Perfekcja', but delayed it in cv. 'Nantejska'. However, ADR-4 improved seed germination to a larger extent than the ceramic dielectric or the magnetic field alone. It increased seed germination capacity and decreased the percentage of diseased seedlings in both samples. All treatments decreased the percentage of dead seeds in cv. 'Nantejska'.

The range of permanent magnetic fields applied to induce seed germination is from several to 500 mT [11], while for alternating magnetic fields it is 0.1 μT÷30 mT, 1 Hz to 100 Hz, respectively [11-14]. Soltani et al [15] found that in a magnetic field of 7 mT asparagus seeds imbibed and germinated more rapidly. Seed germination percentage and epicotyl and hypocotyls lengths were also significantly higher than without the influence of a magnetic field. Carbonnel et al [6] reported that mean germination time of *Festuca arundinacea* Schreb. and *Lolium perenne* L. seeds was reduced by more than 10%, compared with controls, when the seeds were exposed to magnetic fields of 125 mT or 250 mT. The roots of treated grass seedlings were significantly longer than those of untreated ones when seeds were permanently exposed. Florez et al [2] found that the higher germination rate of rice seeds treated with static magnetic fields of 125 mT or 250 mT was in agreement with the higher lengths and weights of rice plants exposed to a magnetic field.

Mano et al [3] found that an extremely low frequency magnetic field (60 Hz, 5 mT) applied to *Arabidopsis thaliana* (L.) Heynh., *Lactuca sativa* L. and *Zinnia elegans* Jacq. seeds suppressed the reduction in germination, caused by seed incubation at high relative humidity (90%) and temperature (37ºC). The authors suggested that the magnetic field suppressed the irreversible deterioration of seeds, preventing water absorption.

The main phenomenon investigated by different authors, found to be responsible for enhanced seed germination capacity and acceleration of morphogenetic processes, is increased water absorption by seeds [14-16]. Water subjected to the action of a magnetic field is altered in a certain way so that it not only penetrates inside seeds faster, but also affects the rate of enzymatic reactions. In the first phase accelerated imbibition is observed in seeds subjected to the action of a magnetic field and their weight increases. Additionally, a plant weight increase may also be connected, apart from effects related with faster metabolism, with higher water content in plants, including fruits [16].

The influence of a magnetic field on seeds may be short-term, e.g. 10 min, followed by the effect in the form of increased water absorption occurring after several hours and lasting for at least several days [14]. This fact is confirmed by the variant, in which an effective action of a magnetic field on plants, including germination, may be replaced by the action on water or substrate which is used to water plants [11, 17]. In this respect it is important to remember that studies on water exposed to the action of a magnetic field indicate an altered, usually reduced, surface tension, viscosity [18], as well as heat of evaporation, manifested in a faster vaporization of such water [11, 19]. These three phenomena are interrelated by the power of actions defined as hydrogen bonds. Changes in these parameters result in a faster penetration of water inside seeds and thus also faster and more effective germination [11, 15]. This facilitated penetration of water solutions is confirmed by a more efficient extraction of chemicals from plant material [20]. Moreover, changes in activity are observed in these enzymes, for which water is involved in the notation of their reaction. Such an enhanced enzymatic activity under the influence of a permanent or alternating magnetic field is observed in case of catalase [21], horseradish peroxidase (the participation of H_3O^+ ion), esterase [11], amylase, protease and lipase [22]. Some of these enzymes participate in seed germination.

The above-mentioned extended action after water or seeds cease to be exposed to the action of a magnetic or electromagnetic field is called water memory. Probably the primary role is played here by the reversal of nuclear spins of hydrogen atoms in the water molecule [23], leading to the parallel or antiparallel orientation of hydrogen nuclear spins in the water molecule and determining the occurrence of two isomers of water - *ortho* and *para*. These isomers are of limited stability and in case of distilled water they spontaneously reach the state of dynamic balance in a matter of several dozen minutes [24]. These isomers affect the formation and stabilization of specific structures of water bound by hydrogen bonds, with an opposite effect also occurring - structures of water strengthened e.g. by the presence of ions may increase many-fold the time, over which water properties changed by the magnetic field are retained [25]. Baran and Degtyarev [26], even before reports on the separation of water into *ortho*- and *para*-isomers was published, had interpreted the influence of a magnetic field on water as its effect on the magnetic moment of protons participating in the hydrogen bond, resulting in a loosening of this bond. In reference to *ortho*- and *para*-hydrogen they also reported that clusters formed by water are controlled by the orientation of proton spins, by which the energy of intermolecular interactions of water in clusters is weakened and ion hydratation in the solution increases [26].

Sensitivity to the action of a magnetic or electromagnetic field covers especially the period from the dry kernel phase before sowing to approx. 17÷24 h swelling period (in case of wheat) [12]. The time of the action of information introduced by the magnetic field is limited, although it lasts for many days. An increase in plant weight at the vegetative stage is much more marked than at the generative stage. For example, after the activation of seeds by a field of 90 mT and 60 Hz for 10 min, the leaf area increment in tomato at the vegetative stage was 58% and at the generative stage it was 22% [4]. Moreover, it was also significant that an advantageous effect of the exposure of seeds to the action of a magnetic field is found mainly in seeds with low viability [1].

Królicka et al [27] found a two-fold higher accumulation of umbelliferone in transformed *Ammi majus* L. callus grown on a medium exposed to ADR-4. Further research on the accumulation of secondary metabolites in *Ammi majus* L. callus treated with ADR-4 or its components separately, as in our experiment, showed the effect of the interaction of the magnetic field and the ceramic dielectric (unpublished data).

The decrease in the number of diseased seedlings or dead seeds observed in our study suggests that the treatments controlled to some extent the growth of fungi. Nagy and Fischl [28] investigated the effect of a static magnetic field of 0.1, 0.5 and 1 mT on the growth of selected phytopathogenic microscopic fungi: *Alternaria alternata* (Fr.) Keissler, *Curvularia inaequalis* (Shear) Boedijn and *Fusarium oxysporum* Schlecht. The magnetic field decreased the growth of colonies by 10%. Lipiec et al [29] found that oscillating magnetic field pulses reduced the number of bacteria *Erwinia carotovora* (Jones) Bergey et al and *Streptomyces scabies* (Thaxter) Waksman et Henrici in a liquid nutrient medium 4 000 times and the number of the fungus *Alternaria solani* (Ellis & Martin) Jones & Grout 30 times.

Conclusions

1. The ADR-4 plate (**A**dvanced **D**ielectric **R**adiation Trap) did not affect the rate and uniformity of germination of carrot seeds.

2. Exposure to ADR-4 improved germination capacity of carrot seeds and decreased the percentage of diseased seedlings in both cultivars. In cv. 'Nantejska' a lower percentage of dead seeds was observed.
3. The ceramic dielectric without magnets accelerated germination of 'Perfekcja' seeds at the initial phase and improved germination capacity and decreased the number of dead seeds in cv. 'Nantejska'.
4. 'Perfekcja' seeds exposed to magnetic field alone germinated faster than untreated seeds, whereas in case of cv. 'Nantejska' a delay in seed germination was found. In cv. 'Perfekcja' a lower percentage of diseased seedlings and in cv. 'Nantejska' an improved germination capacity were observed.

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WPŁYW STAŁEGO POLA MAGNETYCZNEGO Z RÓWNOCZESNYM EKRANOWANIEM PRZEMIENNEGO POLA ELEKTRYCZNEGO NA WIGOR I KIEŁKOWANIE NASION MARCHWI

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Abstrakt: Celem prowadzonych badań było określenie wpływu stałego pola magnetycznego z równoczesnym ekranowaniem przemiennego pola elektrycznego na wigor i kiełkowanie nasion marchwi odmiany ‘Perfekcja’ i ‘Nantejska’. W doświadczeniu wykorzystano urządzenie o nazwie ADR-4 (**A**dvanced **D**ielectric **R**adiation Trap) zbudowane z porowatej ceramiki, w której znajduje się woda w postaci krystalicznej. Tak wytworzony materiał ma silną zdolność do ekranowania przemiennego pola elektrycznego na niskich częstotliwościach, to jest w granicach od 10^{-2} do 10^{6} Hz, przy czym maksimum tangensa delta (stratność pola elektrycznego) poprzez proces technologiczny zostało wyznaczone dla około 50 Hz. Na takiej bazie dielektrycznej umieszczono 10 elementów magnetycznych wykonanych z ferrytobaru o określonej konfiguracji. Przez cały okres kiełkowania nasiona poddano działaniu urządzenia ADR-4, a także samego dielektryku ceramicznego bez elementów magnetycznych oraz samego pola magnetycznego (wyłącznie elementy magnetyczne). Ocenę wigoru i kiełkowania nasion przeprowadzono w temperaturze 20ºC w ciemności. Wigor nasion określono za pomocą parametrów opisujących szybkość i wyrównanie kiełkowania. Przy ocenie kiełkowania nasion określano ogólną liczbę kiełkujących nasion, zdolność kiełkowania, odsetek siewek z objawami chorobowymi i zniekształconych oraz nasion martwych. Poddanie nasion działaniu urządzenia ADR-4 nie wpłynęło na ich wigor, ale stwierdzono poprawę zdolności kiełkowania i zmniejszenie liczby siewek z objawami chorobowymi. U odmiany ‘Nantejska’ obserwowano również mniej nasion martwych niż w kontroli. Zastosowanie samego dielektryka ceramicznego przyspieszyło kiełkowanie nasion odmiany ‘Perfekcja’ w początkowej fazie oraz poprawiło zdolność kiełkowania i zmniejszyło liczbę nasion martwych u odmiany ‘Nantejska’. Nasiona odmiany ‘Perfekcja’ poddane działaniu samego pola magnetycznego kiełkowały szybciej niż nasiona kontrolne, natomiast w przypadku nasion odmiany ‘Nantejska’ stwierdzono opóźnienie kiełkowania. U odmiany ‘Perfekcja’ notowano mniej siewek z objawami chorobowymi, a u odmiany ‘Nantejska’ obserwowano poprawę zdolności kiełkowania nasion.

Słowa kluczowe: stałe pole magnetyczne, zmienne pole elektryczne, marchew, wigor nasion, kiełkowanie