ACTA Acta Sci. Pol., Hortorum Cultus 12(6) 2013, 93-102

DOES THE MAGNETIC FIELD IMPROVE THE QUALITY OF RADISH SEEDS?

Marcela Krawiec, Krzysztof Kornarzyński, Salwina Palonka, Magdalena Kapłan, Piotr Baryła, Piotr Kiczorowski
University of Life Sciences in Lublin

Abstract. The use of high quality sowing material is the fundamental condition for good yielding of crop plants. One of new, unconventional methods of seed quality improvement is low-frequency variable magnetic field. It has been found that this physical factor has a favourable effect on seed germination, emergence and growth of many crop plants. The objective of the study was to determine the effect of low-frequency magnetic field (LFMF) on the germination of radish seeds, with particular emphasis on old seeds. The experimental material were seeds of 7 lots of radish cv. 'Mila', with germination capacity of 66.5–92.5%. The age of the seeds was from 1 to 8 years. Seeds from all the lots were treated with variable magnetic field with frequency of 50 Hz, at 3 doses of magnetic induction as follows: 0 (control), 30 and 60 mT for 30 seconds. Then, the seed germination energy and capacity were determined, as well as the length of the hypocotyl and of the radicle of the seedling, dry weight of seedling, and emergence and mean time of emergence. The low frequency magnetic field exposure (30 and 60 mT) improved radish seed germination energy and capacity of every old seed lot. The increase of germination energy of old seeds amounted to 12.3–19.2%, and the increase of germination capacity was 5.8–10%. Magnetic field stimulation caused the increase of germination energy for 3 out of 4 seed lots of high quality but did not affect the improvement of germination capacity of those lots. No significant effect of magnetic field of seeds on the hypocotyl and radicle elongation was observed with the exception of 1 out of the 7 seed lots. For the 2 old seed lots out of the 3 total, magnetic field treatment caused the increase of emergence by 4.4–13.0%.

Key words: *Raphanus sativus* L., low-frequency magnetic field (LFMF), germination, emergence

Corresponding author: Marcela Krawiec, Department of Seed Production and Nurseries, University of Life Sciences in Lublin, 58 Leszczyńskiego Str., 20-068 Lublin, Poland, e-mail: marcela.krawiec@up.lublin.pl

INTRODUCTION

Radish (*Raphanus sativus* L.) is a vegetable characterised by a very short period of vegetation. Depending on the cultivation conditions and the cultivar, the time from sowing to consumption ripeness varies in the range of 30–50 days. The profitability of early-spring cultivation of radish is largely determined by the possibility of accelerating its harvest readiness. Early yielding of the species is facilitated by rapid germination of seeds and uniform emergence of the plants. Radish production is conducted with the use of various measures aimed at acceleration of germination and emergence, e.g. sowing of graded or/and conditioned seeds, application of covering with plastic films or non-woven fabrics [Słodkowski and Rekowska 2004].

Numerous studies have indicated the low-frequency magnetic field (LFMF) also can affect the improvement of seed quality. Results of experiments have shown that pre-sowing treatment with magnetic field of 125 and 250 mT reduced mean germination time and improved germination rate of tomato seeds to control [Martinez et al. 2009]. Soltani et al. [2006] proved that static magnetic field exposure of 3 mT increased the total number of germinated seeds of sweet basil. Kubisz at al. [2012] reported a positive effect of low frequency magnetic field of 20 mT on the improvement of germination energy and capacity of onion seeds. Moon and Chung [2000] showed that seed treated with 60 Hz magnetic field accelerated their germination and the final germination percentages. Hernandez Aguilar et al. [2009] had exposed maize seeds to LFMF of three magnetic field flux densities (20, 60, 100 mT) have reported the best field emergence after magnetic field with induction of 100 mT. Additionally, some researchers have indicated that the improvement of the seeds germination and seedlings emergence was accompanied by elongation of radicles and primary stem as well as increase of seedling fresh or dry weight [Soltani et al. 2006, Hernandez Aguilar et al. 2009].

Results of the studies have indicated that the efficiency of magnetic field exposure depends on many factors: the magnetic flux densities, frequencies, treatment duration, plant material [Phirke et al. 1996, Pietruszewski 2002, Prokop et al. 2002, Kornarzyński et al. 2004, Hernandez Aguilar et al. 2009, Martinez et al. 2009, Rochalska et al. 2011].

The objective of the study was to determine of the effect of LFMF on the germination of radish seeds of different quality, with particular emphasis on old seeds.

MATERIAL AND METHODS

The experiment was conducted in the years 2008–2009 in the laboratory and on the experimental field of the Department of Horticultural Seed Production and Nurseries, University of Life Sciences, Lublin. The experimental material comprised 7 lots of radish seeds cv. 'Mila' (PlantiCo Gołębiew, Poland). In 2008, seeds from the harvests of 2000, 2004 and 2006 were used in the experiment (denoted as lots 1, 2, 3, respectively), and in 2009 – seeds from harvests of 2001, 2002, 2007 and 2008 (denoted as lots 4, 5, 6 and 7, respectively). Since the economic longevity of radish seeds is accepted as 6 years [Grzesiuk and Kulka 1981], seeds from lots 1, 4 and 5 were considered as the old ones. They were stored in the fridge at 5°C. Table 1 presents the weight of 1000 seeds and seed moisture content during the experiment.

Table 1. Some characteristics of the radish seed lots used in the studies

Year	Seed lot number	Seed harvest year	Weight of 1000 seeds (g)	Moisture content (%)
2008	1	2000	9.62	6.08
	2	2004	10.46	6.34
	3	2006	11.76	6.21
2009	4	2001	9.47	6.18
	5	2002	10.00	6.38
	6	2007	10.77	6.45
	7	2008	10.52	6.59

The seeds of each lot were treated with the LFMF at the following doses:
D0 – seeds untreated, control,
D30 – seeds exposed to LFMF (B = 30 mT, f = 50 Hz for 30 seconds),
D60 – seeds exposed to LFMF (B = 60 mT, f = 50 Hz for 30 seconds).

The stimulation of the seeds was conducted at the Department of Physics, ULS, Lublin. The treatment with variable magnetic field was conducted with the use of the electromagnet designed by Pietruszewski [2000]. That electromagnet generates a variable homogeneous magnetic field with frequency of 50 Hz and it does not alter the temperature of the seeds under stimulation.

After the stimulation of the seeds, estimations of seed germination, seedling vigour and field emergence were performed. For that purpose, the standard germination test was conducted, as well as the seedling growth test. To estimate the emergence, a field experiment was established.

The standard test of germination was made in 4 replications of 100 seed each. After 3 days since seed stimulation, the seeds were sown on moistened double blotting paper. Then they were rolled up and placed upright in containers. The containers were covered with plastic bags. The seeds germinated in a thermostat at temperature of 20°C (±1°C), in darkness. The conditions of the seeds germination followed all routine seed testing rules given by the International Seed Testing Association (ISTA). Energy and capacity of germination were recorded on the 5th and 10th day, respectively. The numbers of normal, abnormal and ungerminated seeds were counted.

The seedling growth test was conducted in 4 replications of 25 seeds. The seeds were placed in one line on moistened double blotting paper. After covering the seeds with the third sheet of paper, they were rolled up, tied with a rubber one centimetre below seeds. Then they were placed upright in containers and covered with plastic bags. The germination conditions were the same as described previously. After10 days, the sets with the seeds were unrolled and the length of the hypocotyl and radicle of every normal seedling were measured. On that basis calculations were made of the mean length of hypocotyl and radicle of the seedlings. Normal seedlings from each replication were dried at temperature of 80°C for 24 hours. In that manner, the dry weight of a single seedling for each lot and treatment was calculated [Hampton and TeKrony 1995].

The field experiment was established at the Felin Experimental Farm of the University of Life Sciences, Lublin. The experiment was set up in the random blocks design, in 4 replications of 100 seeds. The seeds were sown on 28th April, 2008, and 25th May, 2009. Each 100 seeds were sown in a row of 2 m long. From the moment of appearance of the first seedlings, daily counting of the seedlings was done. The counting was continued until the 3rd day since the day when no new seedlings appeared. Based on those measurements, the emergence and the mean time of emergence were calculated. Mean emergence time was calculated according to the Pieper's coefficient:

$$W = \Sigma(d \times pd)/k$$

W – Pieper's cofficient,
p – day of seedlings emergence,
pd – number of seedlings emerged on a given day,
k – number of all emerged seedlings.

The results obtained were processed statistically using the analysis of variance ANOVA (STATISTICA 6.0). Intervals of confidence were determined with the Tukey test at the level of $\alpha = 0.05$.

RESULTS

Depending on the tested seed lot, the germination energy of the control seeds varied within the range from 31.8 to 81.9%. The lowest values of germination energy were recorded for old seeds – lots 1, 4 and 5 (32.5%, 31.8% and 44.2%, respectively). Magnetic field treatment of seeds in 6 out of 7 lots caused a significant increase of germination energy. Old seeds responded the most effectively to magnetic field stimulation. Increase of the germination energy of seeds from those lots was from 12.3 to 19.2%. The germination energy of seeds from the remaining lots increased by 0.5–10%. Among the doses of magnetic induction applied, more favourable effects were observed in the case of the dose of 30 mT. As a result of treatment with magnetic field at the lower induction, a significant increase of germination energy was observed for seeds from lots 1, 2, 3, 4, 5 and 6. The application of magnetic field with induction of 60 mT caused a significant improvement of germination energy of seeds from lots 1, 4 and 5 (tab. 2).

Depending on the tested seed lots, the germination capacity of the control seeds of radish varied within the range of 66.5–92.5%. Fairly low germination capacity was characteristic of the old seeds, denoted as lots 1, 4 and 5 (74.3%, 66.5% and 75.5%, respectively). Magnetic treatment of seeds from old lots (1, 4 and 5) caused a significant increase in germination capacity. That increase amounted to 7–8.1% for seeds from lot 1, 5.8–10% for seeds from lot 4, and 6.8–7.3% for those from lot 5. In the case of seeds from lots 1 and 5, magnetic field stimulation at both doses caused a significant increase in the germination capacity. Whereas, in the case of seeds from lot 4, significant increase of germination capacity was observed as a result of treatment with magnetic field of 60 mT. It was not found out the significant effect of magnetic field exposure on the improvement of seed germination capacity of lots which the age was from 1 to 4 years (lots 2, 3, 6 and 7) (tab. 2).

Table 2. Effect of magnetic field treatment on germination energy and capacity of radish seeds

Year	Seed lot number	Germination energy (%)			Germination capacity (%)		
		magnetic field (mT)			magnetic field (mT)		
		0	30	60	0	30	60
2008	1	32.5 b	44.8 a	48.0 a	74.3 b	82.4 a	81.3 a
	2	74.5 b	81.5 a	75.0 b	92.5 a	95.0 a	94.0 a
	3	72.3 b	82.3 a	74.8 ab	91.3 a	93.0 a	94.8 a
2009	4	31.8 b	47.5 a	51.0 a	66.5 b	72.3 ab	76.5 a
	5	44.2 b	61. a	60.3 a	75.5 b	82.8 a	82.3 a
	6	74.5 b	82.4 a	80.8 ab	88.5 a	88.9 a	90.4 a
	7	81.9 a	83.4 a	84.6 a	88.3 a	92.0 a	93.9 a

Means marked with the same letters in the lines do not differ significantly at $\alpha = 0.05$

For 6 out of 7 tested lots magnetic field treatment had no significant effect on the elongation of the seedling hypocotyl and radicle relative to the control. Magnetic field stimulation affected significantly the increase of hypocotyl and radicle length only in the case of the seed lot 1. Depending on the dose of magnetic field, the increase of seedling hypocotyl and radicle length for this seed lot was 17.8–22.2% and 11.5–17.3% respectively (tab. 3).

Table 3. Effect of magnetic field treatment of radish seeds on hypocotyl and radiclelength of seedling

Year	Seed lot number	Hypocotyl length (cm)			Radicle length (cm)		
		magnetic field (mT)			magnetic field (mT)		
		0	30	60	0	30	60
2008	1	4.5 b	5.3 ab	5.5 a	5.2 b	6.1 a	5.8 a
	2	6.8 a	7.4 a	6.5 a	7.3 a	7.7 a	7.5 a
	3	6.1 a	6.9 a	6.5 a	6.7 a	7.4 a	7.2 a
2009	4	5.1 a	5.4 a	5.2 a	5.4 a	5.9 a	5.5 a
	5	5.9 a	6.5 a	6.1 a	6.9 a	7.3 a	7.2 a
	6	7.7 a	7.9 a	8.1 a	8.8 a	8.8 a	9.2 a
	7	9.5 a	9.7 a	9.5 a	9.8 a	10.5 a	10.3 a

Explanations as in the tab. 2.

Radish seed treatment with magnetic field had no significant effect on the increase of dry weight of seedlings as compared to seedlings developed from control seeds. The dry weights of seedlings received from the seeds treated with the LFMF were bigger than the ones from the control. Because of high variability of the received data, these differences were not proved to be significantly different (data not shown).

Table 4. Effect of pre-sowing treatment magnetic field of radish seeds on emergence

Year	Seed lot number	Emergence (%)		
		magnetic field (mT)		
		0	30	60
2008	1	48.6 b	56.5 a	53.0 a
	2	73.5 a	71.3 a	74.0 a
	3	70.5 a	69.5 a	70.0 a
2009	4	32.5 b	45.5 a	42.3 a
	5	50.8 a	52.3 a	54.0 a
	6	71.3 a	72.5 a	71.5 a
	7	73.3 a	72.5 a	70.8 a

Explanations as in the tab. 2.

The poorest emergences were obtained from sowing the control seeds from the lots 1, 4 and 5 (48.6%, 32.5% and 50.8%, respectively). Emergence of the remaining control treatments were in the range of 70.5–73.5%. The pre-sowing magnetic field treatment of seeds was found to have a significant stimulating effect on emergence achieved for seeds from lots 1 and 4 (for 2 out of 3 old lots). For these seed lots the increase of emergence hesitated from 4,4 to 13,0%. No favourable effect of pre-sowing magnetic field treatment on increase of the emergence of seedlings developed from seeds from the remaining lots was observed (for 5 out of 7 tested lots) (tab. 4).

The magnetic field had no effect on the mean time of emergence (data not shown).

DISCUSSION

In the study, estimation was made of the effect of low-frequency variable magnetic field with induction of 30 and 60 mT on the germination of radish seeds under laboratory conditions and on emergence under field conditions. The study included old seeds, i.e. seeds with lower quality. Stimulation with magnetic field caused an increase of the germination energy of radish seeds. The results support the research by other authors indicating a positive effect of that physical factor on the seeds germination energy of other plant species [Rochalska and Orzeszko-Rywka 2005, Kubisz at al. 2012]. In the study presented here, the most advantageous effects of magnetic stimulation were observed for old seeds, i.e. 7–8 years old (with initial germination capacity of

66.5–75.5%). Their germination energy increased by 12.3–19.2%, depending on the seed lot and value of magnetic induction applied. Increase of germination energy recorded for high quality seed lots varied within the range of 0.5–10%. Germination energy, defined as the ability of seeds to germinate rapidly, is of high practical importance. Seeds with a high germination energy value are less exposed to the negative effect of soil crusting, drought, damage by pests, etc. Seeds with high germination energy give uniform emergence, which ensures uniform development of plants [Grzesiuk and Kulka 1981].

In our experiments the used LFMF increased the germination capacity of old seeds but did not improve it in the case of the high quality seeds. Our results are consistent with the study conducted by Alexander and Doijode [1995], who reported a positive effect of magnetic field with 10.8 mT on low viability onion seeds. In their experiment an initial viability of onion seeds was only 41%. After magnetic field treatment the germination capacity increased up to 56%. Aksenov et al. [1996] found out the rise in the germination percentage of old seeds of wheat when the magnetic field was exposed in the course of swelling. The received results are in accordance with the results obtained by Rochalska [2002a] who found out that magnetic field did not influence on the germination capacity of high quality seeds of spring wheat and spring triticale at optimal conditions. Dziwulska-Hunek et al. [2009] received the same results in the experiment with the seeds of amaranth. They indicated that variable magnetic field had an advantageous effect on germination in the initial phase of that process that lasted from several to several dozen hours.

Radish seed stimulation with magnetic field caused also a significant elongation of the hypocotyl and the radicle of seedlings but only in 1 out of 7 lots. In other cases the received differences were statistically not proved. It was not found out the significant effect of magnetic field exposure on the increase of seedling dry weight of radish seedlings. These results are contrary to those of research by Soltani et al. [2006] and Aksenov et al. [1996] which proved a positive effect of LFMF on elongation of basil seedlings and seedling dry weight of wheat. However, the results of many authors indicated that the effects of LFMF on length and weight of seedlings are depended on many factors i.e. genotypes and treatment duration [Alexander and Doijode 1995, Hernandez Aguilar et al. 2009, Martinez et al. 2009].

According to Pietruszewski and Kania [2010] results noted at various research center are difficult to compare because of different magnetic flux densities, frequencies and exposure times used in different studies. To facilitate a comparison of the results reported by various authors these researchers suggested the use of the exposure dose which accounts for the effect of magnetic and electric fields as well as the time of exposure.

The results obtained by us indicate that treatment of old radish seeds with LFMF (for 2 out of 3 seed lots) causes an improvement of seedling emergence. No increase of emergence was observed in the case of high quality radish seeds. Similar effects were observed by Rochalska [2002b] in a study concerned the effect of stimulation with variable magnetic field on wheat kernels. Only old wheat seeds responded to magnetic field treatment with an increase and acceleration of emergence as compared to control treatments.

Seed ageing has come to be recognized as the major cause of reduced seed vigour and viability. Seed deterioration usually begins at physiological maturity and continues during harvest, processing and storage at a rate greatly influenced by genetic, production and environmental factors. Physiological and physical damage to cell membranes is likely to be the fundamental cause of seed deterioration. But enzyme, respiration and hormonal changes, impaired protein and RNA synthesis, genetic damage, an accumulation of toxic metabolites are also involved. Definitely the cell membrane lost the structural integrity and the protective barrier function before the destructive external factors [Grzesiuk and Kulka 1981, Hampton and TeKrony 1995, Baskin and Baskin 2001].

The mechanism for the stimulating effect of magnetic field on seed germination and seedlings development is still unknown. The results received by Aksenov et al. [1996] indicate activation of metabolism on exposure to a LFMF. Change in pH close to the germ and liberation of proteins hasten the release of the seeds from the resting state probably induces the processes of healing of damage to the membranes and recovery of their barrier function. According to Aksenov et al. [1996] the recovery of the barrier function of the membranes determines the activation of the enzyme systems in old seeds after magnetic field exposure and the rise in the rate of germination of such seeds.

CONCLUSIONS

1. The low frequency magnetic field exposure (30 and 60 mT) improved radish seed germination energy and capacity of every old seed lot.
2. Magnetic field stimulation affected the increase of germination energy for 3 out of 4 seed lots of high quality but did not affect the improvement of germination capacity of those lots.
3. Magnetic field exposure did not affect the increase of hypocotyl and radicle lengths with the exception of 1 out of the 7 seed lots.
4. For the 2 old seed lots out of the 3 total, magnetic field treatment with 30 and 60 mT caused the increase of emergence. The improved emergence hesitated from 4.4 to 13.0%.

REFERENCES

Aksenov S.I., Bulychev A.A., Grunina T.Y., Turovetskii V.B., 1996. Mechanisms of the action of a low-frequency magnetic field on the initial stages of germination of wheat seeds. Biophysics 41(4), 931–937.

Alexander M.P., Doijode S.D., 1995. Electromagnetic field, a novel tool to increase germination and seedling vigour of conserved onion (*Allium cepa* L.) and rice (*Oryza sativa* L.) seeds with low viability. Plant Gen. Res. Newslet. 105, 1–5.

Baskin C.C., Baskin J.M., 2001. Seeds: ecology, biogeography, and evolution of dormancy and germination. Academic Press, California, San Diego.

Dziwulska-Hunek A, Kornarzyński K., Matwijczuk A., Pietruszewski S., Szot B., 2009. Effect of laser and variable magnetic field stimulation on amaranth seeds germination. Int. Agrophys. 23, 229–235.

Grzesiuk S., Kulka K., 1981. Fizjologia i biochemia nasion. PWRiL, Warszawa.
Hernandez Aguilar C., Dominguez-Pacheco A., Carballo A.C. Cruz-Orea A., Ivanov R., Lopez Bonilla J.L., Valcarcel Montanez J.P., 2009. Alternating field irradiation effects on three genotype maize seed field performance. Acta Agrophys. 14(1), 7–17.
Hampton J.G., TeKrony D.M., 1995. Handbook of vigour test methods. ISTA.
Kornarzyński K., Pietruszewski S., Segit Z., Szwed-Urbaś K., Łacek R., 2004. Wstępne badania wpływu stałego i zmiennego pola magnetycznego na szybkość wzrostu kiełków pszenicy. Acta Agroph. 3, 521–528.
Kubisz L., Hołubowicz R., Gauza M., Li H., Hojan-Jezierska D., Jaroszyk F., 2012. Effect of low freguency magnetic field on germination of onion (*Allium cepa* L.) seeds. Acta Phys. Pol. A. 121, 49–53.
Martinez E., Carbonell M.V., Florez M., Amaya J.M., Maqueda R., 2009. Germination of tomato seeds (*Lycopersicon esculentum* L.) under magnetic field. Int. Agrophys. 23, 45–49.
Moon J.D., Chung H.S., 2000. Acceleration of germination of tomato seeds by applying AC electric and magnetic fields. J. Electrostat. 48, 103–114.
Pietruszewski S., 2000. Elektromagnes. Wzór użytkowy. UP RP, 108883, BUP, 11, 78–79.
Pietruszewski S., 2002. Wpływ pól magnetycznych i elektrycznych na kiełkowanie nasion wybranych roślin uprawnych. Techn. Agr. 1(1), 75–81.
Pietruszewski S., Kania K., 2010. Effect of magnetic field on germination and yield of wheat. Int. Agrophys. 24, 297–302.
Prokop M., Pietruszewski S., Kornarzyński K., 2002. Wstępne badania wpływu zmiennych pól magnetycznych i elektrycznych na kiełkowanie, plony oraz cechy mechaniczne korzeni rzodkiewki i rzodkwi. Acta Agroph. 62, 83-93.
Phirke P.S., Kubde A.B., Umbarkar S.P., 1996. The influence of magnetic field on plant growth. Seed Sci. Tech. 24, 375–392.
Rochalska M., 2002a. Pole magnetyczne jako środek poprawy wigoru nasion. Acta Agroph. 62, 103–111.
Rochalska M., 2002b. Poprawa jakości materiału siewnego za pomocą zmiennego pola magnetycznego. Doświadczenia polowe. Acta Agroph. 62, 113–126.
Rochalska M., Orzeszko-Rywka A., 2005. Magnetic field treatment improves seed performance. Seed Sci. Tech. 33, 669–674.
Rochalska M., Grabowska-Topczewska K., Mackiewicz A., 2011. Influence of alternating low frequency magnetic field on improvement of seed quality. Int. Agroph. 25, 265–269.
Soltani F., Kashi A., Arghavani M., 2006. Effect of magnetic field on *Ocimum basilicum* seed germination and seedling growth. Acta Hort. 723, 279–282.
Słodkowski P., Rekowska E., 2004. Efficiency of flat covers on yielding of some vegetable species grown for bunch harvest. Folia Univ. Agric. Stein., Agricult. 234 (93), 361–365.

CZY POLE MAGNETYCZNE WPŁYWA NA POPRAWĘ JAKOŚCI NASION RZODKIEWKI?

Streszczenie. Stosowanie materiału siewnego wysokiej jakości jest podstawowym warunkiem dobrego plonowania roślin uprawnych. Jedną z nowych, niekonwencjonalnych metod uszlachetniania nasion jest zmienne pole magnetyczne niskiej częstotliwości. Stwierdzono korzystny wpływ tego czynnika fizycznego na kiełkowanie nasion, wschody i wzrost wielu roślin uprawnych. Celem badań było określenie wpływu pola magnetycznego niskiej częstotliwości na kiełkowanie nasion rzodkiewki, ze szczególnym uwzględnieniem nasion starych. Materiałem do badań były nasiona 7 partii rzodkiewki odmiany ‘Mila’ o zdolności kiełkowania 66,5–92,5%. Wiek nasion wynosił 1–8 lat. Nasiona wszystkich partii traktowano zmiennym polem magnetycznym o częstości 50 Hz w 3 dawkach indukcji magnetycznej: 0 (kontrola), 30 i 60 mT przez 30 s. Następnie określono energię i zdolność kiełkowania nasion, długość hypokotylu i korzenia siewki, suchą masę siewki oraz wschody i średni czas wschodów. Traktowanie nasion polem magnetycznym o indukcji 30 i 60 mT poprawiło energię i zdolności kiełkowania nasion starych. Wzrost energii i zdolności kiełkowania tych nasion wynosił odpowiednio 12,3–19,2% i 5,8–10%. Stymulacja nasion polem magnetycznym spowodowała wzrost energii kiełkowania 3 z 4 badanych partii nasion wysokiej jakości, ale nie wpłynęła na poprawę ich zdolności kiełkowania. Istotny wpływ traktowania nasion polem magnetycznym na wydłużenie hypokotylu i korzenia siewki stwierdzono jedynie w 1 spośród 7 badanych partii. W przypadku 2 na 3 partie nasion starych traktowanie ich polem magnetycznym spowodowało poprawę wschodów siewek o 4,4–13%.

Słowa kluczowe: *Raphanus sativus* L., pole magnetyczne niskiej częstotliwości, nasiona, kiełkowanie, wschody

Accepted for print: 11.04.2013