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LASER IRRADIATION EFFECTS ON SCORZONERA (*Scorzonera hispanica* L.) SEED GERMINATION AND SEEDLING EMERGENCE

Marcela Krawiec, Agata Dziwulska-Hunek, Agnieszka Sujak, Salwina Palonka
University of Life Sciences in Lublin

Abstract. Laser stimulation is a non-expensive and environmentally safe way of the improving of seeds quality. The objective of the study was to determine the effect of He-Ne laser irradiation on the germination parameters of scorzonera seeds. Seeds were characterized with different quality expressed by germination capacity. Experimental material consisted of 4 lots of scorzonera seeds having initial germination capacity between 50.8 and 93.0%. Seeds were treated with laser He-Ne light of surface power density of 3 $mW \cdot cm^{-2}$ and the time of exposition of 0 (control), 1, 5, 10 and 30 minutes. After pre-sowing stimulation of seeds the following parameters were estimated: germination energy, germination capacity, mean germination time, speed of germination, hypocotyl length, length of radicle, fresh and dry weight of seedling, field emergence, mean emergence time and speed of emergence. Pre-sowing laser treatment resulted in increasing of the several parameters such as germination energy, germination capacity, speed of germination, hypocotyl and radicle length, as well as fresh and dry weight of seedlings. Laser light stimulation was the most effective in the case of low quality seeds (initial germination capacity of 50.8%). Irradiation of the seeds belonging to this group also resulted in the increase of the seedling emergence and the speed of emergence.

Key words: scorzonera, He-Ne laser light, seed quality, germination capacity, emergence

INTRODUCTION

S*corzonera hispanica* L. is known like a root vegetable mostly in Europe. It is called a scorzonera, black salsify, black oyster plant or viper's grass. Black salsify, which originates from Southern Europe, is a perennial frost-hardy meadow plant. In cultivation it is treated like a biennial. In first year it forms a leaf rosette and a taproot, up to 0.5 m

Corresponding author: Marcela Krawiec, University of Life Sciences in Lublin, Poland, Leszczyńskiego 58 Street, 20-068 Lublin, e-mail: marcela.krawiec@up.lublin.pl

long, that has a milky white interior with dark brown or blackish skin. It is the taproot which is most often eaten as a vegetable. Young leaves are used as a salad. In the second year, the inflorescence stems and seeds are formed [Nuez and Bermejo 1994, Kilian et al. 2009]. Roots of this vegetable may be consumed raw, cooked and as well as frozen or canned food [Nuez and Bermejo 1994]. Scorzonera is known for the high content of polysaccharide inulin in its root. This compound as a prebiotic stimulates growth of the useful intestinal bacteria (*Bifidobacteria* species and other bacteria), thanks to making the operation of the alimentary canal more efficient, thus preventing constipation [Kelly 2008].

Scorzonera is propagated from the seed. The achenes are 10 to 20 mm long, cylindrical, whitish and rough [Nuez and Bermejo 1994]. Scorzonera belongs to vegetables which seed quite quickly loose its viability. Under good storage conditions seed maintain a high germination capacity for only two years [Stephens 1994].

Therefore the challenge of the modern agriculture is to accomplish high crop yield of the cultivated plants with usage of environmentally friendly agricultural methods. The important factor increasing crop is usage of a high quality sowing material characterized with high germination capacity and delivery of the rapid and uniform seedling emergence. Laser light irradiation, magnetic or electric field treatment are the environmentally friendly physical methods of improving seed quality [Pietruszewski 2002, Soltani et al. 2006, Gładyszewska 2011]. Particularly beneficial effects were observed after application of laser light. Laser is the device producing monochromatic and coherent light with a parallel beams. Due to a very narrow emission line and a parallel beams it is possible to focus the laser radiation within the very defined area and to obtain a relatively high power density [Hoffmann 1996]. The laser stimulation method uses the physical phenomenon consisting of the ability to absorb and store light energy, transform into chemical energy, store it and use it in the growth, later [Gładyszewska 2011]. In most experiments He-Ne lasers are applied. Single cases of application of semiconducting, argon or CO_2 lasers happen. Domination of the He-Ne lasers is strictly connected to its characteristic wavelength of 632.4 nm which corresponds to red light assigned as having the positive effect on plants [Dziwulska 2006].

Experiments conducted in different laboratories indicate the positive effect of irradiation of the seeds on the growth and development of the cultivating plants. Results obtained by different groups indicate that the pre-sowing laser treatment influences mostly the process of seed germination and the seedling growth at the very early stages [Dziwulska 2006, Muszyński and Gładyszewska 2008, Dziwulska-Hunek et al. 2009, Soliman and Harith 2010, Sujak et al. 2013]. Some authors showed that in some cases the effects of laser irradiation occur also in the later development stages which results in the increasing of the crop yield, improvement of crop quality, acceleration of the plant growth and ripening, increase of the plant mineral content or the increase of the plant resistance to stress [Vasilevski and Bosev 1997, Truchliński et al. 2002, Podleśny and Podleśna 2004, Sujak et al. 2009, Ćwintal and Dziwulska-Hunek 2013].

Many authors demonstrate that the success of stimulation caused by monochromatic and low intensity laser light is dependent on wavelength, irradiation time and irradiation dose [Rybiński 2000, Hernandez et al. 2006, 2010, Soliman and Harith 2010]. Lower doses of laser light activate plants, resulting in increasing bioenergetical potential of the cell and higher activation of their biochemical and physiological processes. Higher doses influence genetical material of the cell leading to genetic changes of plant traits [Rybiński 2000].

Usually the seeds of high quality were subjected to experiments on the effect of the pre-sowing laser irradiation. Often unexpected circumstances force to sow the seeds of the reduced quality such as old, defective or improperly stored. Such sowing material produces weak and thinned out field emergences what negatively affects the crop yield. The objective of the presented study was to determine the effect of laser irradiation on the germination of scorzonera seeds of different quality and on its emergence.

MATERIAL AND METHODS

Experiments were conducted in the year 2013 in the Department of Physics and in the Department of Horticultural Seed Production and Nursery of the Life Sciences University in Lublin, Poland. The experimental material consisted of 4 lots of scorzonera seeds cv. 'Maxima'. Seeds collected in the years 2009, 2010, 2011 and 2012 (marked as lots 1, 2, 3 and 4, respectively) were used. Seeds were characterized with different quality expressed by an initial germination capacity (tab. 2). Seeds were stored in the fridge at the temperature of 5°C. The meteorological conditions in the years of seed harvest were very similar and did not differ the germination capacity. While measuring 3 months after harvest it oscillated between 85 and 90%.

Seeds were stimulated with the He-Ne light of a surface power density of 3 $mW \cdot cm^{-2}$ and the exposition times of 0 (control), 1, 5, 10 and 30 min. The appliance using the method of variable energy doses was used [Koper 1996] with the vertical direction of interacting with seeds He-Ne laser beam. Laser beam falled from the top onto the seeds equally distributed underneath. The exposition time was measured with a timer.

The following parameters were estimated after pre-sowing seed stimulation with laser light: germination energy, germination capacity, mean germination time, speed of germination, hypocotyl length, length of radicle, fresh and dry weight of seedling, field emergence, mean emergence time and speed of emergence.

The assessment of the selected germination parameters was conducted under the standard germination test done in 4 repetitions on 100 of seeds from each experimental setting. Seeds were sown on moistened double blotting paper on the day following laser stimulation. 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 ISTA [2004].

The germination energy (expressed in terms of the rate of normally germinating seeds) was calculated after 4 days from sowing the seeds on blotting paper, while the germination capacity was estimated after 8 days [ISTA 2004]. Everyday counting of the normally germinating seeds allowed for estimation of the mean germination time based on Pieper's coefficient [W] and of the speed of the germination based on the Maguire coefficient [E] [1962].

The mean germination time was estimated from the following equation:

$$W = \Sigma(d \times pd)/k \text{ (days)},$$

W – Pieper's coefficient,
d – day of seeds germination,
pd – number of normally germinating seeds in given day,
k – total number of the normally germinating seeds.

The speed of germination was calculated according to the following equation [Maguire 1962]:

$$E = \frac{k_1}{t_1} + \frac{k_2}{t_2} + \frac{k_n}{t_n} \text{ (number of germinated seeds/1 day)},$$

E – Maguire coefficient,
k – number of normally seeds germinating in the subsequent observation days,
t – number of days from the day of sowing.

Based on the seedling growth test, the hypocotyl and the radicle lengths and the fresh and dry seedling weight were estimated. 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. After 8 days the length of hypocotyl and radicle as well as the weight of single normal seedling were determined. 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].

Field experiment was done by using a randomized complete block design (RCB) in 4 repetitions of 100 seeds. The field experiment was conducted at the Felin Experimental Farm of the University of Life Sciences in Lublin (51°23' N, 22°56' E) on a grey-brown podzolic soil developed from loess formations over lying chalk marls, with a grain size composition corresponding to that of weak silty loams. Seeds were sown on the 8th of May 2013. Each 100 seeds were sown in a row of 2 m long. Upon the appearance of the first seedlings, the number of seedlings was registered at two-days interval. The counting was continued until the 22nd of May 2013 (until 2nd day since the day when no new seedlings appeared). The seedbed environment conditions were: mean temperature of 16.9°C, maximum temperature of 26.1°C, minimum temperature of 6.2°C, the precipitation amount during the time of experiment was the same as the mean perennial sum. Based on those observations, the emergence, the mean emergence time and speed of emergence were calculated. Mean emergence time was calculated according to the Pieper's coefficient. The speed of germination was calculated according to the definition of Maguire coefficient [Maguire 1962].

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

RESULTS

The examined lots of scorzonera seeds differed considerably with their germination energy. Seeds from lot 1 showed the lowest initial germination energy (6.5%), while the seeds from lot 3 had the highest initial germination energy (58.5%). He-Ne laser light pre-sowing treatment of seeds resulted in the increase of the germination energy although in some cases no statistically significant effect was observed. The maximal increase of the seed germination energy amounted from 8.8 (lot 3) to 42.2% (lot 4) as compared to control. In the case of 3 from 4 examined seed lots (lots 1, 2 and 4) the most noticeable effects of laser treatment on the germination energy were recorded for the exposition time of 30 minutes. In the case of lot 1 the laser irradiation was the most effective. At the exposition times of 10 and 30 min the germination energy increased 2-fold, which justify usage of pre-sowing laser stimulation for improving the sowing quality of seeds (tab. 1).

Table 1. Effect of He-Ne laser light treatment on germination energy of scorzonera seeds

Exposure time (min)	Germination energy (%)			
	seed lots			
	1	2	3	4
0	6.50 c ±3.42	24.25 c ±4.35	58.50 a ±6.61	32.00 d ±3.27
1	6.75 c ±2.50	34.75 ab ±0.96	63.50 a ±3.42	46.25 bc ±1.71
5	8.50 bc ±1.91	34.50 ab ±5.00	67.25 a ±0.96	54.50 b ±8.23
10	13.00 ab ±2.58	27.75 bc ±1.71	60.50 a ±3.41	39.50 cd ±3.42
30	15.75 a ±1.71	36.25 a ±2.87	63.00 a ±6.22	74.15 a ±3.50

± standard deviation.
Means with different letters in the same column are statistically different at p = 0.05

Germination tests of scorzonera seeds under laboratory conditions showed that the germination capacity of the control seeds amounted from 50.8% (lot 1) to 93.0% (lot 3). Seeds from lot 1 didn’t satisfy the requirements of Polish standards (PN-R-67050) for the sowing material as their germination capacity was lower than the 70%.

Pre-sowing stimulation with the laser light of the seeds from lots 1, 2 and 4 resulted in the increase of the germination capacity, although the effect was not always statistically significant. Solely seeds from lot 1 responded with the statistically significant increase in germination parameters for all the used exposition doses. In that case the increase of germination capacity amounted to 18.3–25.8% depending on the exposition time. The maximum level of the increase of germination capacity for the other lots came out to 5.0–14.0% as compared to control. In the case of seeds from lot 3 laser irradiation lasting 1, 10 and 30 min resulted in the decrease of the germination capacity as compared to control (tab. 2); the differences were not statistically significant.

Laser light stimulation had an effect on the shortening of the mean germination time of scorzonera seeds expressed in the Pieper’s coefficient although in the most cases no `statistical differences were found. The mean time of germination of scorzonera seed was shortened by 0.11–0.35 day after laser treatment in the case of lots 1–3. The most effective effect of laser stimulation was registered for the seeds from lot 4, where the mean germination time shortened statistically significant by 0.73–1.61 day, depending on the exposition time (tab. 3).

Table 2. Effect of He-Ne laser light treatment on germination capacity of scorzonera seeds

Exposure time (min)	Germination capacity (%)			
	seed lots			
	1	2	3	4
0	50.75 b ±7.37	71.00 b ±2.58	93.00 b ±2.00	79.25 c ±0.96
1	76.50 a ±1.00	77.25 ab ±5.25	90.75 b ±2.50	87.50 b ±3.42
5	72.50 a ±1.00	78.75 ab ±2.50	98.00 a ±0.01	86.75 b ±0.96
10	74.25 a ±6.24	80.25 a ±5.91	92.00 b ±1.63	84.00 bc ±3.27
30	69.00 a ±2.00	76.00 ab ±0.01	92.00 b ±3.27	93.25 a ±0.96

Explanations as in the table 1

Table 3. Effect of He-Ne laser light treatment on mean germination time of scorzonera seed (Pieper's coefficient)

Exposure time (min)	Mean germination time (days)			
	seed lots			
	1	2	3	4
0	8.35 b ±0.12	7.08 b ±0.03	6.51 b ±0.14	7.57 d ±0.03
1	8.18 ab ±0.10	6.80 a ±0.16	6.27 a ±0.11	6.83 c ±0.05
5	8.21 ab ±0.10	6.93 ab ±0.10	6.28 a ±0.04	6.45 b ±0.22
10	8.23 ab ±0.15	6.97 ab ±0.07	6.18 a ±0.07	6.84 c ±0.10
30	8.00 a ±0.20	6.83 a ±0.10	6.38 ab ±0.08	5.96 a ±0.10

Explanations as in the table 1

For lots 1, 2 and 4 laser stimulation at all the applied exposition doses produced significant acceleration of germination of the laser-stimulated seeds as expressed by a Maguire's coefficient. Seeds from lot 3 responded exclusively on irradiation with the exposure time of 5 minutes. As the result of stimulation the number of seeds germinated during one day increased by 1.32–4.81, depending on experimental lot and the exposition time (tab. 4).

Statistically significant elongation of hypocotyl of the scorzonera seedling was registered for lot 4 for all the exposition doses. For other lots no statistically significant effects were detected. The highest increase of the hypocotyl length from the all seed lots stimulated with laser light for 10 min was observed. Depending on seed lot it amounted between 8.4–25.9% (tab. 5).

Table 4. Effect of He-Ne laser light treatment on speed of scorzonera seed germination (Maguire coefficient)

Exposure time (min)	Speed of germination (number of germinated seeds day^{-1})			
	seed lots			
	1	2	3	4
0	6.36 b ±0.91	10.21 b ±0.42	14.86 b ±0.61	11.22 d ±0.16
1	9.40 a ±0,19	11.96 a ±0.65	14.95 b ±0.23	13.55 bc ±0.53
5	9.04 a ±0.24	11.87 a ±0.51	16.18 a ±0.01	14.04 b ±0.55
10	9.36 a ±0.63	11.88 a ±0.74	15.37 ab ±0.31	12.79 c ±0.42
30	8.94 a ±0.14	11.58 a ±0.12	14.98 b ±0.55	16.03 a ±0.38

Explanations as in the table 1

Table 5. Effect of seed pre-treatment with He-Ne laser light on the length of hypocotyl

Exposure time (min)	Length of hypocotyl (cm)			
	seed lots			
	1	2	3	4
0	2.00 a ±0.12	2.58 a ±0.15	2.63 a ±0.13	2.05 b ±0.13
1	2.20 a ±0.08	2.58 a ±0.19	2.68 a ±0.19	2.38 a ±0.17
5	2.28 a ±0.15	2.70 a ±0.26	2.78 a ±0.17	2.38 a ±0.10
10	2.38 a ±0.25	2.90 a ±0.36	2.85 a ±0.34	2.58 a ±0.10
30	2.33 a ±0.21	2.58 a ±0.21	2.73 a ±0.13	2.53 a ±0.21

Explanations as in the table 1

For lots 1 and 4 the increase of the seedling radicle length as an effect of laser light stimulation was observed. Statistically significant effect for all the exposition doses was observed only for lot 1. Depending on the exposition time, the radicle elongation was between 31.3–45.0%. Statistically significant effect of the increase of the radicle length (42.6%) of seedlings for lot 4 was registered only in the case of exposition time of 30 minutes. Depending on exposition time, the laser light stimulation had a positive or negative effect on that parameter for lots 2 and 3 (tab. 6).

Generally, pre-sowing laser light treatment with all the exposition doses had a positive influence on the increase of the seedling fresh weight. For lots 1 and 4 the observed increase was statistically significant and amounted 17.2–40.4% and 42.3–66.3%, respectively as compared to control. The significant influence on the increase of the seedling fresh weight of 30 min laser irradiation was found for lots 2, 3 and 4 (tab. 7).

Table 6. Effect of seed pre-treatment with He-Ne laser light on the length of radicle

Exposure time (min)	Length of radicle (cm)			
	seed lots			
	1	2	3	4
0	1.98 b ±0.34	3.60 a ±0.42	3.98 a ±0.67	2.70 b ±0.67
1	2.95 a ±0.24	3.45 a ±0.42	3.93 a ±0.43	3.53 ab ±0.43
5	2.62 a ±0.21	3.60 a ±0.22	4.30 a ±0.63	3.40 ab ±0.63
10	2.65 a ±0.42	3.38 a ±0.10	3.83 a ±0.21	3.35 ab ±0.21
30	2.60 a ±0.18	3.25 a ±0.21	4.75 a ±0.50	3.85 a ±0.50

Explanations as in the table 1

Table 7. Effect of seed pre-treatment with He-Ne laser light on fresh weight of seedling

Exposure time (min)	Fresh weight of seedling (mg)			
	seed lots			
	1	2	3	4
0	33.16 c ±2.05	42.02 b ±3.17	51.86 b ±4.61	30.89 b ±3.54
1	41.63 ab ±1.70	48.24 ab ±2.63	58.35 ab ±2.94	48.91 a ±3.23
5	43.50 ab ±3.48	46.78 ab ±2.38	58.78 ab ±5.85	43.94 a ±4.32
10	46.54 a ±3.63	46.57 ab ±2.88	50.69 b ±4.60	45.55 a ±3.23
30	38.85 b ±0.58	51.38 a ±3.14	61.80 a ±2.74	51.38 a ±5.45

Explanations as in the table 1

Table 8. Effect of seed pre-treatment with He-Ne laser light on dry weight of seedling

Exposure time (min)	Dry weight of seedling (mg)			
	seed lots			
	1	2	3	4
0	2.08 c ±0.12	2.20 b ±0.19	2.73 b ±0.14	1.56 b ±0.21
1	2.28 bc ±0.21	2.38 ab ±0.14	2.92 ab ±0.20	2.54 a ±0.06
5	2.52 ab ±0.16	2.48 ab ±0.19	2.87 ab ±0.18	2.21 a ±0.38
10	2.72 a ±0.28	2.35 ab ±0.15	2.71 b ±0.06	2.24 a ±0.18
30	2.26 bc ±0.08	2.76 a ±0.28	3.13 a ±0.09	2.59 a ±0.13

Explanations as in the table 1

Stimulation of the scorzonera seeds belonging to all lots resulted in the increase of the seedling dry weight. Irradiation of the seeds from lot 4 for all the exposition time resulted in significant increase of the seedling dry weight (41.7–66.0%). For the seeds from lot 1 irradiation for the time of 5 and 10 minutes and for the seeds from lots 2 and 3 irradiation lasting 30 minutes produced significant increase of the dry seedling weight (tab. 8).

Table 9. Effect of seed pre-treatment with He-Ne laser light on field emergence (%)

Exposure time (min)	Field emergence (%) seed lots 1	2	3	4
0	37.50 b ±3.00	54.75 a ±2.50	66.75 a ±7.46	53.25 a ±6.02
1	42.00 ab ±5.51	53.25 a ±3.20	69.75 a ±2.63	52.50 a ±5.72
5	43.50 ab ±4.12	57.00 a ±8.08	58.25 a ±3.50	51.25 a ±4.99
10	44.50 ab ±3.42	50.75 a ±0.96	64.00 a ±8.16	57.00 a ±6.39
30	47.50 a ±4.12	57.25 a ±0.96	63.50 a ±8.06	59.75 a ±4.27

Explanations as in the table 1

Table 10. Effect of seed pre-treatment with He-Ne laser light on speed of emergence (Maguire coefficient)

Exposure time (min)	Speed of emergence (number of emerged seedlings day^{-1}) seed lots 1	2	3	4
0	3.77 b ±0.30	4.40 a ±0.43	5.03 a ±0.27	4.23 a ±0.55
1	4.12 ab ±0.34	3.98 a ±0.33	4.84 a ±0.54	4.21 a ±0.53
5	4.51 ab ±0.53	4.34 a ±0.28	5.69 a ±0.66	4.19 a ±0.29
10	4.49 ab ±0.41	4.38 a ±0.16	5.36 a ±0.66	4.70 a ±0.41
30	4.65 a ±0.41	4.63 a ±0.29	4.74 a ±0.58	4.54 a ±0.50

Explanations as in the table 1

The poorest field emergence was obtained from control seeds of lot 1 (37.5% on average). Field emergences of other controls amounted from 53.25 (lot 4) to 66.75% (lot 3). The beneficial effect of pre-sowing laser irradiation was observed for the seedlings from the lot 1. Solely, 30-minutes laser stimulation of the seeds resulted in the significant increase of the emerged seedling as compared to control. One cannot explicitly confirm the positive effect of irradiation of seeds with He-Ne laser light on field emergence from other lots. Similarly to seeds from lot 1, for lots 2 and 4 the highest field emergences were observed upon 30-minutes irradiation (tab. 9). The pre-sowing laser irradiation had no effect on the mean time of emergence (data not shown).

The speed of emergence for the control samples expressed by the Maguire's coefficient varied from 3.77 seedlings day^{-1} for lot 1 to 5.03 seedlings day^{-1} for lot 3. Stimulation of the seeds from lot 1 and all the exposition times resulted in the increase the speed of emergence, but only 30-minute irradiation had a significant effect on the acceleration of emergence (tab. 10).

DISCUSSION

In the presented study the effect of pre-sowing laser stimulation on the germination of the scorzonera seeds of different initial quality and the emergence were examined. Seeds consisted of 4 lots with initial germination capacity between 50.8 and 93.0%. The laser light treatment resulted in the increase of the germination energy and capacity, the increase of the germination speed, elongation of seedling hypocotyl and radicle as well as the increase of fresh and dry weight of seedling. Similar results were also obtained by other authors upon experiments done on other species [Wilczek et al. 2005, Dziwulska 2006, Muszyński and Gładyszewska 2008, Dziwulska-Hunek et al. 2009, Soliman and Harith 2010].

Laser light stimulation was the most effective on germination capacity of the seeds with low quality (initial germination capacity of 50.8% – lot 1). Depending on the exposition dose the increase of germination capacity for this lot amounted to 18.2–25.7%. It means that, due to the laser irradiation the seeds reached the germination capacity of at least 70%, the minimum standard germination required for scorzonera seed commercialization in Poland. Slightly smaller effect of laser light treatment on the germination capacity was observed for the medium quality seed lots 2 and 4 (5.0–9.3% and 4.8–14.0%, respectively). The exceptionally good results in the case of treatment of low physiological quality seeds (stimulation with He-Ne laser light, electromagnetic field) are confirmed by the work of other authors. Experiments conducted by Krawiec and Dziwulska-Hunek [2009] on old seeds of peas with using He-Ne laser light indicate the increase of the germination energy and capacity. Alexander and Doijode [1995] reported a positive effect of magnetic field on low viability onion seeds. On the other hand, stimulation with electric field resulted in the 50% increase of the germination capacity of low viability tomato seeds [Pietruszewski 2002]. In our study, seeds of relatively high germination capacity (93% – lot 3) responded negatively (decrease of this parameter) to three different irradiation doses. Such a phenomenon is partially consistent with the study obtained by Roszko and Michalik [2002], where laser light – stimulated carrot seeds of the high quality didn't show the improvement of the germination capacity as compared to control. Similarly, Rochalska [2002a] demonstrated that other physical factor (alternating magnetic field) did not influence on the germination capacity of high quality seeds of spring wheat and spring triticale. Sujak et al. [2013] conveyed the laboratory and pot experiments on the influence of physical factors (laser light, alternating magnetic field and combination of these factors) on germination energy and germination capacity of old seeds of yellow and angustifolius lupine as well as on lucerne. It was shown varied influence of electromagnetic factors on coarse-grained and small-seed leguminous plant.

In the presented study the result of He-Ne laser light stimulation was the increase of the germination energy. The highest observed increase of this parameter, depending on the seed lot, amounted between 8.8–42.2%. The germination energy, in other words the capacity of seeds to fast germination has a practical aspect. A result of higher energy of germination is often, stronger development of radicle, increased fresh mass of the whole seedling and thereafter a plant. This, usually, results in better plant useful characters, e.g. yield of roots, bulbs or leaves [Copeland and McDonald 1995]. Our studies, where the increase in the germination energy was accompanied with the increase of the radicle length and with the increase of scorzonera seedlings weight, acknowledge this opinion. He-Ne laser stimulation of scorzonera seeds resulted in the elongation of hypocotyl and radicle of the seedling and in the increase of its fresh and dry weight. Similar effects were observed in case of lupine and broad-bean [Podleśny and Stochmal 2004] as well as of cucumber [Drozd and Szajsner 2007] seeds of a relatively high viability. In the presented studies the beneficial results of He-Ne laser light stimulation were found out also in case of low quality seeds. This results were consistent with findings of Alexander and Doijode [1995], who showed the increase of length and weight of the onion and rice seedlings as a result of pre-sowing stimulation of the seeds with electromagnetic field.

The positive effect of the laser light on the increase of the germination speed was found. Calculations done on the basis of the Maguire's coefficient proved that the number of the seeds germinated during a single day increased by 0.09–4.81, depending on the experimental seed lot and the exposition time. On the other hand, calculations based on Pieper's coefficient showed that, depending on lot and time of exposure, upon irradiation, the time of germination of a single seed shortened by 0.11–1.67 day. Similar effect of a minor shortening of the seed germination time upon laser irradiation was reported by Muszyński and Gładyszewska [2008]. Our studies show that in some cases the process of germination of a single seed subjected to laser irradiation can be accelerated by more than 1 day as compared to control. This being the case, the period of the vegetative growth of plants grown from irradiated seeds can be longer as compared to control, which can have further impact on the crop yield.

According to ISTA regulations the assessment of the germination should be conducted under laboratory conditions optimized for the given species. The field emergence, particularly during early spring, progress under conditions unfavourable for germination. Therefore the problem of the influence of the pre-sowing He-Ne laser treatment of scorzonera seeds on their field emergence is very important. The results obtained in this study indicate that the pre-sowing laser light stimulation affected the increase and acceleration of the emergence of seedlings obtained from low quality scorzonera seeds (lot 1). Similar effects were observed by Hernandez et al. [2006] as a result of irradiation of the maize seeds with low initial germination capacity. In our study no increase or acceleration of the emergence were observed for scorzonera seeds with medium and high initial indices (lots 2–4). The corresponding data (although the applied pre-sowing stimulation factor was alternating magnetic field) was obtained for wheat kernels by Rochalska [2002b]. In that work only wheat seeds of low quality responded with the increase and acceleration of the emergence as compared to control.

Generally, the exposure time of the scorzonera seeds on the laser light within the range between 1 and 30 minutes didn't have a significant effect on the analyzed parameters. On the other hand, in the case of some indices (germination energy, fresh and dry seedling weight, emergence and speed of emergence) the most beneficial values were obtained after 30–minutes light stimulation. The results of other authors indicate that the combination of the exposure time of the seeds on the laser light and the surface power density may have a very significant effect on seed germination, field emergence as cell as on crop yield. He-Ne laser light treatment of the *Acacia farnesiana* L. seeds during 1, 3, 5, 7 and 9 min and the doses of 0.03, 0.20, 0.61, 1.14 and 1.70 W·cm^{-2} resulted in the increase of the germination indices (time to germinate, germination period, germination percentage, germination speed) as compared to control. The longer the exposition time and higher dose, the more beneficial effect was observed [Soliman and Harith 2010]. On the other hand experiments done by Hernandez et al. [2006] on laser He-Ne irradiation of the surface power density of 20 $mW \cdot cm^{-2}$ and the exposition time of 60 s resulted in the increase of maize seedlings emergence and on the mean time of emergence in comparison with the exposition times of 30, 120, 180, 300, and 600 s. Rybiński [2000] showed that pre-sowing treatment of the spring barley seeds with the laser light of the surface power density of 1 $mW \cdot cm^{-2}$ and the exposition time of 30 minutes improved the quality and quantity of the crop grain, while in the case of the exposition time of 120 minutes the reduction of the crop yield was observed.

Based on the results of the experiments obtained in this survey it may be generally stated that the effects of irradiation depend not only on the applied wavelengths and exposition doses but also on the species and initial quality of the seeds. It must be argued that the exposition dose should be adjusted individually to the species and the quality of seed lot.

CONCLUSIONS

1. He-Ne laser irradiation of different quality scorzonera seeds affected the increase of energy germination, shortening of mean germination time and the increase of germination speed as compared to control.
2. Pre-sowing laser stimulation resulted in the increase of seed germination capacity of low and medium quality seeds as compared to control. The seed of high quality responded the decrease of this parameter to the irradiation of 3 exposition doses.
3. Laser light treatment of scorzonera seeds affected the elongation of seedling hypocotyl and radicle, resulted in the increase of fresh and dry seedling weight.
4. Clear beneficial effect of laser light treatment demonstrated by the improvement of emergence in the case of low quality seeds was observed. The stimulation with all doses resulted in the increase and acceleration of emergence.
5. Generally, the laser irradiation of scorzonera seeds of the exposure times between 1 and 30 minutes didn't have a significant effect on the analyzed parameters. But in the case of germination energy, fresh and dry seedling weight, emergence and speed of emergence the most beneficial values were obtained after 30-minutes light stimulation.

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WPŁYW PROMIENIOWANIA LASEROWEGO NA KIEŁKOWANIE NASION I WSCHODY SIEWEK SKORZONERY (*Scorzonera hispanica* L.)

Streszczenie. Stymulacja laserowa jest tanim i bezpiecznym dla środowiska sposobem uszlachetniania nasion. Celem badań było określenie wpływu przedsiewnej stymulacji laserem He-Ne na kiełkowanie charakteryzujących się różną jakością nasion skorzonery oraz na wschody siewek. Jakość nasion wyrażono za pomocą zdolności kiełkowania. Materiałem do badań były nasiona 4 partii skorzonery o początkowej zdolności kiełkowania od 50.8 do 93.0%. Nasiona skorzonery stymulowano światłem lasera He-Ne o powierzchniowej gęstości mocy 3 $mW \cdot cm^{-2}$ w czasie 0 (kontrola), 1, 5, 10 i 30 min. Po stymulacji laserowej oceniono energię kiełkowania, zdolność kiełkowania, średni czas kiełkowania, szybkość kiełkowania, długość hypokotylu i korzenia siewki, świeżą i suchą masę siewki, wschody polowe, średni czas wschodów i szybkość wschodów. Traktowanie nasion światłem lasera wpłynęło na wzrost energii i zdolności kiełkowania, wzrost szybkości kiełkowania, wydłużenie hypokotylu i korzenia siewki oraz zwiększenie świeżej i suchej masy siewek wykształconych z tych nasion. Stymulacja światłem lasera najefektywniej wpłynęła na poprawę zdolności kiełkowania nasion niskiej jakości (o wyjściowej zdolności kiełkowania 50.8%). Naświetlanie nasion należących do tej partii spowodowało również zwiększenie wschodów i wzrost szybkości wschodów.

Słowa kluczowe: skorzonera, światło lasera He-Ne, jakość nasion, zdolność kiełkowania, wschody

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