AGRONOMY SCIENCE
wcześniej – formerly
Annales UMCS sectio E Agricultura
VOL. LXXVII (3) 2022
CC BY
http://doi.org/10.24326/as.2022.3.7

[1] Department of Biophysics, University of Life Sciences in Lublin, Akademicka 13, 20-950 Lublin, Poland
[2] Department of Agricultural, Forest and Transport Machinery, University of Life Sciences in Lublin, Głęboka 28, 20-612 Lublin, Poland
[3] Department of Strategy and Business Planning, Faculty of Management, Lublin University of Technology, Nadbystrzycka 38, 20-618 Lublin, Poland

*e-mail: agata.dziwulska-hunek@up.lublin.pl

AGATA DZIWULSKA-HUNEK[1]*, MARIUSZ SZYMANEK[2], JACEK DZIWULSKI[3]

Managing the quality of seeds from cereal conditioned with effective microorganisms (EM) and red light (RL)

Zarządzanie jakością nasion zbóż kondycjonowanych efektywnymi mikroorganizmami (EM) i światłem czerwonym (RL)

Summary. The study pertained to environmentally-friendly methods in the cultivation of cereal, and aimed to manage the quality of rye and triticale seeds and determine the impact of seed conditioning using effective microorganisms (EM), red light (RL), and a combination of the two (RL × EM) on the yield of grain and straw. Moreover, the seeds were sown into soil with and without EM conditioning, designated as 0 and PEM. The yield fluctuations depended mostly on the studied rye and triticale cultivars. The best effects we observed in soil without EM conditioning for Dańkowskie Złote rye and Moderato triticale. The increase in grain and straw yields was, respectively: 26% (RL), 31% (RL × EM), 40% (EM), and 17% (RL × EM), 23% (RL), 32% (EM) – Dańkowskie Złote, 27% (RL × EM), 44% (EM), 46% (RL), and 17% (RL × EM), 51% (EM), 78% (RL) – Moderato. In turn, seeds exposed to the experimental treatment and sown into soil containing EM produced reduced yields in both of the above cultivars. It is noteworthy that the conditioning methods employed in the field experiment can facilitate increased yields but most importantly contribute to the resilience of agrosystems and can therefore have environmental benefits.

Key words: seed quality management, effective microorganisms, halogen floodlights, rye, triticale, yield

INTRODUCTION

In the current context of sustainable agricultural development, it remains necessary to continuously satisfy consumer demand for agricultural and horticultural products. This can be accomplished through adequate management. Strategies should stem from correct cultivation aimed at obtaining high quality seeds and agricultural produce. Correct cultivation means safe and healthy soil-plant-environment [Wezel et al. 2014, Velten et al. 2015]. The problem of deteriorating seed vigour stems from the continuous effects of undesirable and harmful factors during cultivation, harvest, and storage [Jyoti and Malik 2013]. In agricultural practice, various solutions are constantly considered with a view to securing plentiful harvests, most commonly entailing the use of large quantities of pesticides and chemical fertilizers. Although effective, these are not necessarily safe nor beneficial to public health. Good yields and high harvest efficiency are usually secured at the expense of biological quality of the soil. It is of key importance that the soil's fertility is continuously improved through the activity of microorganisms and earthworms that maintain its physicochemical properties by metabolising biodegradable and organic materials [Singh 2018]. Management of soil quality in plant and animal production is a very important aspect of sustainable agricultural development and requires the soil to be used adequately [Bai et al. 2018]. Moreover, seed quality is a key factor conditioning yields in agricultural production and is in itself dependent on proper management in the course of cultivation, harvest, storage, and preparation for sowing [Rajjou et al. 2006, Rao et al. 2017]. Hence, the use of appropriate and environmentally friendly cultivation methods in plant production is vital to the achievement of desired yields as well as preservation of soil fertility. The same must be safe for the soil environment but also take human and animal health into due consideration. One of such methods entails the use of effective microorganisms (EM) – soil treatment, seed treatment [Seran and Suthamathy 2013, Sangakkara et al. 2014, Gajewski 2016]. An EM biopreparation (effective microorganisms, EM-farming, ProBi Ema) contains a carefully selected composition of aerobic and anaerobic microorganisms (lactic acid bacteria, yeast, fungi, actinobacteria, phototrophic bacteria) [Radkowski and Radkowska 2018, Borowy et al. 2018]. EM technology was first developed by Teuro Higa from the Ryukus University on Okinawa in Japan, and relied on a special, careful selection of effective microorganisms [Javaid and Shah 2010, Javaid and Bajwa 2011, Borowy et al. 2018]. Some microorganisms can impact the metabolism, modification, or use of dangerous (toxic) substances. It is a process known as biodegradation, which entails the removal and processing of toxins present in chemical substances [Tang et al. 2007]. Moreover, microorganisms have the ability to evenly self-distribute in soil. The growth and activity of microorganisms are affected by temperature, humidity, soil pH and composition, solubility in water, as well as availability of oxygen and nutrients [Abatenh et al. 2017].

Other environmentally-friendly approaches also entail the use of physical stimuli such as: red light (He-Ne laser, halogen floodlights, etc.), magnetic fields, gamma radiation, etc. [Pietruszewski et al. 2007, Muszyński et al. 2009, Hernández et al. 2010, Matwijczuk et al. 2012, Govindaraj et al. 2017, Kataria et al. 2017 Dziwulska-Hunek et al. 2020]. Light plays a key role in plant life as it is necessary for the process of photosynthesis producing organic matter, and as a morphogenic factor responsible for plant growth and development (germination, phototropism, formation of buds and leaves, regulation of photosynthetic pigments content [Gotto 2003]. Stimulating seeds with red light can affect their germination capacity and later plant yield [Hernández et al. 2010, Ćwintal and Dziwulska-Hunek 2013, Dziwulska-Hunek et al. 2020, Hasan et al. 2020]. Moreover, in a study related to the effect of red light stimulation on the protein content in triticale grain, there was an increase of 10.2% to 16.2% compared to unstimulated seeds. The content of minerals in the grain was also increased, particularly for sodium, zinc, and iron [Truchliński et al. 2002].

The mechanism of laser light stimulation is based on the absorption and storage of light energy, which can be later converted to chemical energy. This affects such stages of plant development as germination and growth. Nonetheless, despite significant scientific and technological advances the exact mechanism remains unknown. Plant life still holds many secrets [Sulkiewicz and Ciereszko 2016].

There are few reports in Polish and international literature discussing the pre-sowing treatment of rye and triticale seeds with effective microorganisms and red light. The available reports from EM studies were either limited to a narrow group of plants or combined with mineral fertilizer tests. The mechanisms of plant development continue to hold many secrets despite the continuous advances in science and technology. This inspired us to approach this particular research problem.

The study aimed to manage seed quality and analyse the impact of seed conditioning with effective microorganisms, red light, and the combination of the two factors on the yields of grain and straw (rye, triticale). Moreover, the effects of PEM (soil containing effective microorganisms) content in the soil on the yields was also considered.

MATERIAL NAD METHODS

Plant material

The research material consisted of seeds from three rye cultivars: Dańkowskie Złote, Dańkowskie Diament, Pop IA and three triticale cultivars: Moderato, Witon, Gernado, obtained from the Plant Breeding and Acclimatization Experimental Station in Radzików. Rye and triticale cultivars recommended by the National Register of Cultivated Plants [Drążkiewicz et al. 2019, COBORU 2022].

The field experiment was conducted between 2017 and 2019 at the Experimental Farm of the University of Life Sciences in Lublin located in Felin (51°13'21.9"N, 22°37'55.85"E). The soil at the Experimental Farm was formed from light dusty clay and is classified as good wheat complex. The grain harvest was collected from the experimental surface of 30 m^2. Measurements for each experimental variant were performed in four replicates.

The method for conditioning seeds with red light and EM biopreparation

Before being sown, the seeds were conditioned in the following combinations: with red light (RL), with effective microorganisms (EM biopreparation), or with a combination of the two (first with red light and then with the biopreparation – RL × EM). Seeds unconditioned with either red light or the PEM biopreparation (soil containing effective microorganisms) served as the control (C).

One day before sowing, the seeds were treated with light generated from halogen floodlights at the wavelength of 650–670 nm and stream density of 110–130 $W \cdot m^{-1}$. The exposition time for a single grain was 0.1 s.

The method of pre-sowing seed conditioning entailed exposing both sides of a single layer of grains directly to red light. The devise used for this purpose (Fig. 1) consisted of a dispenser (a) with an outlet hole (b), a vibrating chute (c) with an adjustable element at the end (d) forming a gap (e) with the edge of the chute (c). Below, at least two halogen floodlights (g) were mounted on the device's frame (h). A vibration actuator (i) was

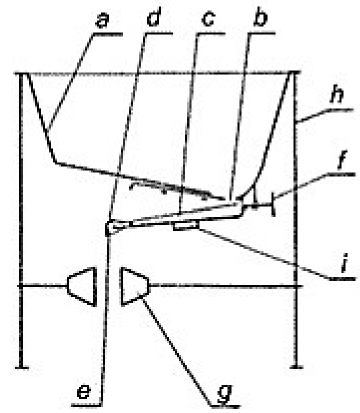

Fig. 1. Light treatment device: a – dispenser, b – outlet, c – chute, d – adjustable element, e – gap, f – adjustment screw, g – halogen floodlights, h – cover, i – vibration actuator [Zarębski and Dziamba 1993]

mounted on the chute (c). Such pre-sowing treatment is typically used on crop seeds with the aim of improving yield quality and quantity (Fig. 1) [Zarębski and Dziamba 1997].

The EM biopreparation was applied annually into the soil at the dose of 40 $dm^3 \cdot ha^{-1}$ EM-A as well as in the form of seed treatment, by soaking seeds in a previously prepared solution (0.3 dm^3 EM-A + 0.7 dm^3 H_2O) for 1 h.

Statistical analysis

The obtained research results were evaluated with the use of variance analysis. Where significant differences were confirmed between variants on the basis of the significance test *F*, quantitative interference was performed relative to Tukey's confidence intervals at the significance level of $p < 0.05$. The accuracy of respective measurement results was determined by considering additional 95% confidence intervals for the arithmetic mean. The calculations were conducted using STATISTICA 13.0 PL software.

RESULTS

Yield of rye grain and straw

The results in terms of rye harvest yield are presented in Table 1. The respective rye cultivars responded differently to the experimental factors applied.

In the variant without microorganism soil treatment, positive effects of the experimental factors were observed for the Dańskowskie Złote cultivar. Depending on the factor, the grain yield increased by between 26% and 40%. The Pop IA cultivar showed no positive response to the experimental factors as the grain yield in this population decreased in the respective variants by between 23% and 39%. The Dańkowskie Diament cultivar showed the best response to the RL treatment. In this case, the grain yield increased by 59%. In the remaining variants, decreased yields were observed. Positive response to the application of microorganisms into the soil was observed only for the Dańkowskie Złote cultivar (45% increase). In the case of Pop IA and Dańkowskie Diament cultivars, the grain yields decreased by between 4% and 15%. As for the Dańkowskie Diament cultivar, the best response was recorded for the combination of the two treatments (increase by 13%). Separate application of RL exposure or EM treatment resulted in a decrease in grain yield in each of the analysed cultivars.

In terms of straw yields, the observed trends were similar. Regardless of the cultivar, the analysed factors triggered, in most variants, an increase in straw yield.

Table 1. Rye grain and straw yields ($kg \cdot m^{-2}$) in respective experimental variants

Cultivar	Variant	Grain		Straw	
		0	PEM	0	PEM
Dańkowskie Złote	C	1.043 (0.002)^{c}	1.508 (0.003)^{a}	1.387 (0.024)^{d}	1.870 (0.016)^{a}
	RL	1.311 (0.015)^{b}	1.099 (0.003)^{c}	1.704 (0.024)^{b}	1.462 (0.017)^{b}
	EM	1.454 (0.018)^{a}	0.807 (0.003)^{d}	1.831 (0.027)^{a}	1.251 (0.024)^{c}
	RL x EM	1.364 (0.003)^{b}	1.103 (0.003)^{b}	1.623 (0.027)^{c}	1.588 (0.011)^{b}
	Mean	1.294	1.129	1.636	1.543
Dańkowskie Diament	C	1.066 (0.015)^{a}	0.909 (0.003)^{b}	1.354 (0.014)^{b}	1.145 (0.024)^{b}
	RL	1.696 (0.012)^{a}	1.123 (0.003)^{a}	1.815 (0.027)^{a}	1.561 (0.019)^{a}
	EM	0.920 (0.013)^{c}	0.880 (0.003)^{b}	1.030 (0.027)^{c}	1.426 (0.024)^{b}
	RL x EM	0.971 (0.014)^{b}	1.100 (0.003)^{a}	1.340 (0.019)^{b}	1.397 (0.027)^{b}
	Mean	1.163	1.003	1.385	1.382
Pop IA	C	1.694 (0.012)^{a}	1.584 (0.003)^{a}	2.210 (0.026)^{a}	2.408 (0.014)^{a}
	RL	1.008 (0.023)^{c}	0.823 (0.003)^{d}	1.089 (0.024)^{c}	1.226 (0.031)^{c}
	EM	1.252 (0.014)^{b}	1.023 (0.003)^{c}	1.578 (0.049)^{b}	1.320 (0.018)^{c}
	RL x EM	1.172 (0.0010)^{a}	1.137 (0.003)^{b}	1.465 (0.024)^{b}	1.558 (0.014)^{b}
	Mean	1.270	1.142	1.586	1.628
Cultivar mean	C	1.253 (0.024)^{b}	1.334 (0.003)^{a}	1.650 (0.014)^{a}	1.808 (0.026)^{a}
	RL	1.338 (0.002)^{a}	1.015 (0.003)^{b}	1.536 (0.011)^{b}	1.416 (0.24)^{b}
	EM	1.210 (0.033)^{b}	0.903 (0.018)^{c}	1.480 (0.024)^{c}	1.332 (0.015)^{c}
	RL × EM	1.169 (0.016)^{c}	1.113 (0.024)^{b}	1.476 (0.017)^{c}	1.514 (0.027)^{b}
	Mean	1.242	1.091	1.636	1.518

0 – control plot w/o EM in the soil, PEM – plot treated with the EM biopreparation – for three years in a column. The same letters in the columns signify non-significant statistical differences.
C – control, RL – red light, EM – biopreparation, RL × EM – red light plus EM as treatment in a row.

Yield of triticale grain and straw

The obtained results in terms of triticale harvests are presented in Table 2. The respective triticale cultivars responded with either increase or decrease of the grain and straw yields. A greater diversity in terms of grain yields under the influence of the experimental treatments was recorded in the part where soil had not been conditioned with EM.

The Moderato cultivar responded to each of the studied factors with increased grain yields.

However, the highest yield increase was observed in the variants where RL exposure or EM treatment was applied exclusively. In those cases, the yield grew by between 44% and 46%. A small yield increase under the influence of the factors was recorded for the Gredano cultivar (4–6%), while the Witon cultivar produced the highest yield in the RL × EM variant (56% increase). As for the variants where the soil had been conditioned with EM, positive effects were observed only for Witon (45% increase) and Moderato (32% increase) plants. The grain yield from Grenado plants grown in this variant was 15% lower than in the control. Similarly, in other variants the harvests were significantly smaller. For the Moderato cultivar, the best results in this variant were observed after joint RL × EM treatment (18% increase). Witon plants returned the highest yield in the RL variant (15% increase).

Table 2. Triticale grain and straw yields (kg·m^{-2}) in respective experimental variants

Cultivar	Variant	Grain		Straw	
		0	PEM	0	PEM
Moderato	C	1.099 (0.021)^{c}	1.455 (0.011)^{b}	1.330 (0.015)^{c}	1.790 (0.013)^{b}
	RL	1.604 (0.015)^{a}	1.068 (0.014)^{d}	2.037 (0.018)^{a}	1.346 (0.014)^{c}
	EM	1.585 (0.017)^{a}	1.352 (0.021)^{c}	2.013 (0.018)^{a}	1.960 (0.017)^{a}
	RL × EM	1.392 (0.009)^{b}	1.641 (0.024)^{a}	1.684 (0.020)^{b}	1.969 (0.015)^{a}
	Mean	1.420	1.379	1.766	1.766
Witon	C	1.433 (0.012)^{c}	2.074 (0.024)^{a}	1.605 (0.026)^{b}	2.344 (0.011)^{a}
	RL	1.505 (0.021)^{b}	1.724 (0.026)^{b}	1.339 (0.021)^{c}	1.879 (0.015)^{b}
	EM	1.367 (0.018)^{d}	1.473 (0.024)^{c}	1.340 (0.015)^{c}	1.694 (0.012)^{c}
	RL × EM	2.229 (0.017)^{a}	1.702 (0.017)^{b}	2.225 (0.018)^{a}	1.855 (0.017)^{b}
	Mean	1.643	1.743	1.627	1.943
Grenado	C	1.576 (0.013)^{a}	1.337 (0.022)^{a}	1.702 (0.017)^{b}	1.738 (0.013)^{b}
	RL	1.636 (0.012)^{a}	0.516 (0.017)^{c}	2.225 (0.024)^{a}	2.062 (0.010)^{a}
	EM	1.664 (0.011)^{a}	1.194 (0.016)^{b}	1.398 (0.021)^{c}	1.385 (0.024)^{c}
	RL × EM	1.148 (0.010)^{b}	1.144 (0.013)^{b}	1.148 (0.018)^{d}	1.430 (0.018)^{c}
	Mean	1.506	1.298	1.618	1.654
Cultivar mean	C	1.369 (0.015)^{c}	1.622 (0.015)^{a}	1.546 (0.015)^{c}	1.957 (0.019)^{a}
	RL	1.582 (0.015)^{a}	1.436 (0.015)^{b}	1.867 (0.015)^{a}	1.762 (0.024)^{b}
	EM	1.539 (0.015)^{b}	1.340 (0.015)^{c}	1.584 (0.015)^{c}	1.680 (0.025)^{b}
	RL × EM	1.590 (0.015)^{a}	1.496 (0.015)^{b}	1.686 (0.015)^{b}	1.751 (0.021)^{b}
	Mean	1.520	1.473	1.670	1.788

Explanation as in Table 1.

As for straw yields, depending on the variant various levels of increase were recorded. It should be noted, however, that yield fluctuations were considerably less pronounced for straw as compared to grain, particularly in the variant with EM soil treatment. In the variant without soil conditioning, Moderato and Grenado plants produced the greatest yield after RL treatment. In the case of the Witon cultivar, better effects were observed for combiner RL and EM biopreparation treatment. It should be noted that both Moderato and Witon plants returned the highest yields in the variant with EM-conditioned soil.

Grenado cultivar produced a higher straw yield under the combined influence of irradiation and microorganisms (EM).

DISCUSSION

In a field experiment conducted by Ghersa et al. [1994] the impact of light on the yield of winter wheat was studied. When the total irradiation was reduced to approx. 10% of full sunlight, the yield of wheat grain dropped by 40% in the presence of Italian rye-grass, as compared to wheat grown in the absence of weeds and with access to full sunlight.

The quality of seeds is affected by a number of factors such as cultivar and analytic purity, germination capacity, vigour, and health [Boelt et al. 2018]. As follows from a laboratory study conducted by Gładyszewska [2006], the impact of He-Ne laser light stimulation on the germination capacity of rye and wheat was the highest in seeds harvested in 2005 at a temperature of 15°C. As reported by Drozd and Szajsner [2001], laser biostimulation was observed to affect seed germination, increasing the energy (up to 7%) and germination capacity (up to 2%) of triticale seeds. In our own studies, we observed increased grain yields in all triticale cultivars and two rye cultivars under the influence of red light stimulation, respectively by 44–46% and 26–59%. The use of the method facilitates higher yields from the aforementioned crops while being complexly harmless to the environment, people, and animals. Moreover, it has been reported that the yield and quality of corn improved by 20–48% after light conditioning [Dziwulska-Hunek et al. 2020]. According to Hasan et al. [2020], laser light stimulation had a positive impact on corn yields, with the best effects observed for seeds irradiated with red and blue light for 105 s and green light for 85 s. In other reports, seed stimulation with infrared light (IR) increased the germination rate in four wheat cultivars. The maximum observed germination rate was reported after 3 days and reached 93.3% after 1200 seconds of light stimulation [Abdelghafar et al. 2008]. Moreover, in a study on He-Ne light stimulation, the processing intensified the response to drought in wheat seedlings [Qiu et al. 2017]. Influence of red light (RL) and the use of effective microorganisms (EM) was observed in a study on the growth, grain and straw yield in two wheat cultivars [Szymanek et al. 2020]. Michtchenko and Hernández [2010] observed an increase in the number of wheat seeds germinating correctly and decrease in those germinating incorrectly under the influence of stimulation with laser light at the wavelength of 980 nm with exposure time of 30 and 60 s.

In particular, their effectiveness can be limited due to factors related to land inhomogeneity and unpredictable environmental factors [Khare and Arora 2014]. Tołoczko et al. [2009] and Gajewski [2016] reported absence of a significant influence of effective microorganisms on the structural properties of soil with light and medium consistency.

The use of effective microorganisms can trigger an increase in both quality and quantity of crop yields. At the same time, it is conducive to environmental management systems. Ems include lactic acid bacteria which inhibit the growth of *Fusarium* fungi – a constant problem in agriculture. EM conditioning has been reported to increase cucumber yields and reduce the incidence of pathogen infections [Cóndor_Golec et al. 2007]. They also enrich soil and improve its fertility [Cóndor_Golec et al. 2007, Joshi et al. 2019]. Singh [2018] noted that microorganisms and earthworms influence a number of soil properties including its fertility, which determines the rate of plant growth and yields in natural ecosystems. It has been reported that the use of compost containing effective microorganisms in a long-term field experiment (11 years) led to an increase in wheat yields [Hu and Qi 2013]. In a study conducted by Piskier [2006], the yield of wheat grain increased by 23% after the application of an EM biopreparation. The research results presented here evidence that effective microorganisms had a different impact on the yields of rye and triticale. Increased yields were recorded for rye: Dańkowskie Złote (by 40%), and for triticale: Grenado (6%) and Moderato (44%). In a study involving buckwheat and millet, no clear influence of effective microorganisms was observed, but the same had a positive effect on the quality of soil [Jaroszewska et al. 2019]. In a study involving a three-year application of an EM preparation, increased content of phosphorus and potassium in the soil was reported [Radkowski and Radkowska 2018]. Notably, in our experiment conditioning soil with EM actually resulted in a decrease in rye and triticale yields.

In a study conducted by Gawęda el al. [2018], a significant increase in the yield from soya seeds was observed after the use of mineral fertilizers with additional spraying with effective microorganisms, particularly in the pre-florescence phase. In another study on the use of EM under an ecological regime conducted for 4 years in Central European climate conditions, no improvement in terms of yield or soil quality was observed [Mayer et al. 2010]. Furthermore, a decrease in the yield of grain and straw from Zyta wheat plants was reported after the use of EM [Szymanek el al. 2020].

To recapitulate, proper management of seed quality can lead to increased yields of crops and vegetables, which would be beneficial for both producers and consumers. Contemporary agriculture ought to develop in environmentally-friendly directions. Indeed, consumers are now actively looking for pro-environmental, healthy, and safe products. As economic and social crises affect a growing number of countries, strategic solutions are needed that would facilitate the development of more sustainable agriculture. Our study pertained to techniques that could be effectively used to the benefit of agrotechnical production. Consistent use for a number of years is bound to prove beneficial.

In our experimental studies carried out on small plots, the yields obtained were higher than the actual ones carried out on large areas (in hectares). These studies are an incentive to continue them in field conditions over large areas.

CONCLUSIONS

1. The studied rye and triticale cultivars showed a varied response to seed conditioning using light (RL), effective microorganisms (EM) and a combination thereof (RL × EM) in soil conditioned and not conditioned with EM.

2. The use of red light on rye seeds sown into the soil without EM induced an increase in the yield of grain and straw in two cultivars: Dańkowskie Złote and Dańkowskie Diament.

3. Increased grain and straw yields were observed for all triticale cultivars in soil without EM. Conversely, soil conditioning with EM reduced the yields of grain and straw.

4. The best overall results were observed in the RL × EM variant for Dańkowskie Złote rye and Moderato triticale, in soli without EM.

5. The experiment results show that positive effects could be evidenced for some cereal types, but it should also be noted that, above all, red light and EM seed conditioning is an environmentally-friendly practice that promises to have long-terms effects on the agrosystem.

6. Seed quality management is a key aspect of agriculture and depends on a variety of contributing factors. The RL and RL × EM strategies have a potential for application in seed production with a view to improving their quality in an environmentally-friendly manner.

7. Further study into the applicability of the discussed techniques is necessary as they promise to contribute to a more sustainable and environmentally-friendly large-scale agriculture.

REFERENCES

Abatenh E., Gizaw B., Tsegaye Z., Wassie M., 2017. The Role of microorganisms in ioremediation – a review. Open J. Environ. Biol. 2, 30–46.

Abdelhafer M., Abu-Elsaoud A.M., Tuleukhanov S.T., Abdel-Kader D.Z., 2008. Effect of infra-red laser on wheat (*Triticum aestivum*) germination. Int. J. Agric. Res. 3, 433–438. https://doi.org/10.3923/IJAR.2008.433.438

Bai Z., Caspari T., Gonzalez M.R., Batjes N.H., Mäder P., Bünemann E.K., De Goede R., Brussaard L., Xu M., Ferreira C.S.S., Rentam E., Fan H., Mihelič R., Glavan M., Tóth Z., 2018. Effects of agricultural management practices on soil quality: A review of long-term experiments for Europe and China. Agric. Ecosyst. Environ. 265, 1–7. https://doi.org/10.1016/J.AGEE.2018.05.028

Boelt B., Shrestha S., Salimi Z., Jørgensen J.R., Nicolaisen M., Carstensen J.M., 2018. Multispectral imaging – a new tool in seed quality assessment?. Seed Sci. Res. 28(3), 222–228. https://doi.org/10.1017/S0960258518000235

Borowy A., Kapłan M., Krawiec M., 2018. Impact of effective microorganisms on weed infestation and yield of peppermint cultivated on muck-peat soil. Acta Agrobot. 71(4), 1755. https://doi.org/10.5586/aa.1755

COBORU, 2022. Centralny Ośrodek Badania Odmian Roślin Uprawnych [Research Centre for Cultivar Testing], https://coboru.gov.pl [date of access: 31.05.2022].

Cóndor_Golec A.F., Pérez G., Lokare Ch., 2007. Effective microorganisms: myt hor reality? Microorganismos eficaces: mito o realidad?. Rev. Peru. Biol. 14(2), 315–319.

Ćwintal M., Dziwulska-Hunek A., 2013. Effect of electromagnetic stimulation of alfalfa seeds. Int. Agrophys. 27, 391–401. https://doi.org/10.2478/intag-2013-0009

Drążkiewicz K., Janiak W., Najewski A., Piecuch K., Skrzypek A., Szarzyńska J., 2019. Lista opisowa odmian roślin rolniczych 2019 [Descriptive list of agricultural plant cultivars 2019]. Centralny Ośrodek Badania Odmian Roślin Uprawnych, Słupia Wielka [in Polish] https://coboru.gov.pl/Publikacje_COBORU/Listy_opisowe/LOORR%20-%20zbozowe%202019.pdf [date of access: 30.04.2019].

Drozd D., Szajsner H., 2001. Efekt biostymulacji laserowej u roślin zbożowych. Biul. Inst. Hod. Aklim. Rośl. 218/219, 235–239.

Dziwulska-Hunek, A., Szymanek M., Stadnik J., 2020. Impact of pre-sowing red light treatment of sweet corn seeds on the quality and quantity of yield. Agriculture 10(165), 1–10. https://doi.org/10.3390/agriculture10050165

Gajewski P., 2016. Influence of the EM-A preparation on the structure properties in various mineral soils. Soil Sci. Annu. 67(4), 179–184. https://doi.org/10.1515/ssa-2016-0022

Gawęda D., Haliniarz M., Woźniak A., Harasim E., 2018. Yield, seed quality and nodule formation of soybean under application of effective microorganisms. Acta Agrophys. 25, 35–43. https://doi.org/https://doi.org/10.31545/aagr0003

Ghersa C.M., Martinez-Ghersa M.A., Casal J.J., Kaufman M., Roush M.L., Deregibus V.A., 1994. Effect of light on winter wheat (*Triticum aestivum*) and Italian Ryegrass (*Lolium multiflorum*) competition. Weed Technol. 8, 37–45.

Gładyszewska B., 2006. Pre-sowing laser biostimulation of cereal grains. Tech. Sci. 9, 33–38.

Gotto E., 2003. Effects of light quality on growth of crop plants under artificial lighting. Environ. Control Biol. 41(2), 121–132.

Govindaraj M., Masilamani P., Alex Albert V., Bhaskaran M., 2017. Effect of physical seed treatment on yield and quality of crops: A review. Agric. Rev. 38(1), 1–14. https://doi.org/10.18805/AG.V0IOF.7304

Hasan M., Hanafiah M.M., Taha Z.A., Alhilfy I.H.H., Said M.N.M., 2020. Laser irradiation effects at different wavelengths on phenology and yield components of pretreated maize seed. Appl. Sci. 10, 1189, 1–12. https://doi.org/10.3390/app10031189

Hernández A.C., Dominguez P.A., Cruz O.A., Ivanov R., Carballo C.A., Zepeda B.R., 2010. Laser in agriculture. Int. Agrophys. 24, 407–422.

Hu Ch., Qi Y., 2013. Long-term effective microorganisms application promote growth and increase yields and nutrition of wheat in China. Eur. J. Agron. 46, 63–67. https://doi.org/10.1016/j.eja.2012.12.003

Jaroszewska A., Sobolewska M., Podsiadło C., Stankowski S., 2019. The effect of fertilization and effective microorganisms on buckwheat and millet. Acta Agrophys. 26(3), 15–28. https://doi.org/10.31545/aagr/114016

Javaid A., Bajwa R., 2011. Field evaluation of effective microorganisms (EM) application for growth nodulation and nutrition of mung bean. Turk. J. Agric. For. 35, 443–452. https://doi.org/10.3906/tar-1001-599

Javaid A., Shah M.B.M., 2010. Growth and yield response of wheat to EM (effective microorganisms) and parthenium green manure. Afr. J. Biotechnol. 9(23), 3373–3381.

Joshi H., Somduttand Choudhary P., Mundra S.L., 2019. Role of effective microorganisms (EM) in sustainable agriculture. Int. J. Curr. Microbiol. App. Sci. 8(3), 172–181. https://doi.org/10.20546/ijcmas.2019.803.024

Jyoti, Malik C.P., 2013. Seed deterioration: a review. Int. J. Life Sci. Biotechnol. Pharma Res. 2(3), 374–385.

Kataria S., Baghel L., Guruprasad K.N., 2017. Pre-treatment of seeds with static magnetic field improves germination and early growth characteristics under salt stress in maize and soybean. Biocatal. Agric. Biotechnol. 10, 83–90. https://doi.org/10.1016/j.bcab.2017.02.010

Khare E., Arora N.K., 2014. Effects of soil environment on field efficacy of microbial inoculants. In Plant Microbes Symbiosis: Applied Facets, Springer, New Delhi, 353–381. https://doi.org/10.1007/978-81-322-2068-8_19

Mayer J., Sceid S., Widmer F., Fließbach A., Oberholzer H.R., 2010. How effective are ‘Efective Microorganisms (EM)’? Results from a field study in temperate climate. Appl. Soil Ecol. 46, 230–239. https://doi.org/10.1016/j.apsoil.2010.08.007

Michtchenko A., Hernández M., 2010 Photobiostimulation of germination and early growth of wheat seeds (*Triticum aestivum* L) by a 980 nm semiconductor laser. Rev. Cub. Fís. 27(2B), 271–274.

Matwijczuk A., Kornarzyński K., Pietruszewski S., 2012. Effect of magnetic field on seed germination and seedling growth of sunflower. Int. Agrophys. 26(3), 271–278. https://doi.org/10.2478/v10247-012-0039-1

Muszyński S., Gagoś M., Pietruszewski S., 2009. Short-term pre-germination exposure to ELF magnetic field does not influence seedling growth in Durum Wheat (*Triticum durum*). Pol. J. Environ. Stud. 18, 1065–1072.

Pietruszewski S., Muszyński S., Dziwulska A., 2007. Electromagnetic fields and electromagnetic radiation as non-invasive external simulations for seeds (selected methods and responses). Int. Agrophys. 21, 95–100.

Piskier T., 2006. Reaction of spring wheat to the application of bio-stimulators and soil absorbents. J. Re. Appl. Agric. Engin. 51(2), 136–138.

Qiu Z., Yuan M., He Y., Li Y., Zhang L. 2017. Physiological and transcriptome analysis of He-Ne laser pretreated wheat seedlings in response to drought stress. Sci. Rep. 7, 1–12. https://doi.org/10.1038/s41598-017-06518-z

Radkowski A., Radkowska I., 2018. Influence of effective microorganisms on the dry matter yield and chemical composition of meadow vegetation. J. Elem. 23(2), 509–520. https://doi.org/10.5601/jelem.2017.22.3.1441

Rajjou L., Lovigny Y., Job C., Belghazi M., Groot S., Job D., 2006. Seed quality and germination. In: S. Adkins, S. Ashmore, S. Navie (eds.), Seeds: biology, development and ecology. CAB International, 324–331.

Rao N.K., Dulloo M.E., Engels J.M.M., 2017. A review of factors that influence the production of quality seed for long-term conservation in genebanks. Genet. Resour. Crop Evol. 64, 1061–1074. https://doi.org/10.1007/s10722-016-0425-9

Sangakkara R., Wijesinghe D., Attanayake K.B., 2014. Soil quality and crop yields as affected by microbial inoculants in nature farming. In: G. Rahmann, U. Aksoy (eds.), Proceedings of the 4th ISOFAR Scientific Conference. 'Building Organic Bridges', at the Organic World Congress 2014, 13–15 OCt., Istanbul, Turkey, 987–990.

Singh J., 2018. Role of earthworm in sustainable agriculture. In: C.M. Galanakis (ed.), Sustainable food systems from agriculture to industry. Improving production and processing, Academic Press, London, 83–122. https://doi.org/10.1016/B978-0-12-811935-8.00003-2

Seran T.H., Suthamathy N., 2013. Effect of combined application of cattle manure and EM on the yield and yield components of groundnut (*Arachis hypogaea* L.). Bangladesh J. Agril. Res. 38(1), 1–9.

Sulkiewicz M., Ciereszko I., 2016. Fluorescencja chlorofilu a – historia odkrycia i zastosowanie w badaniach roślin [Chlorophyll a fluorescence – history of discovery and pratical application in environmental plant science]. KOSMOS 65(1), 103–115.

Szymanek M., Dziwulska-Hunek A., Zarajczyk J., Michałek S., Tanaś W., 2020. The influence of red light (RL) and effective microorganism (EM) application on soil properties, yield, and quality in wheat cultivation. Agronomy 10, 1201. https://doi.org/10.3390/agronomy10081201

Tang C.Y., Criddle C.S., Leckie J.O., 2007. Effect of flux (trans membrane pressure) and membranes properties on fouling and rejection of reverse osmosis and nano filtration membranes treating perfluorooctane sulfonate containing waste water. Environ. Sci. Technol. 41, 2008–2014.

Tołoczko W., Trawczyńska A., Niewiadomski A., 2009. Zawartość związków próchnicznych w glebach nawożonych preparatem EM [Content of humic substances in soil fertilized with an EM preparation]. Rocz. Glebozn. 60(1), 97–101.

Truchliński J., Wesołowski M., Koper R., Dziamba S., 2002. Influence of pre-sowing red light radiation on the content of antinutritional factors, mineral elements and basic nutritional component contents in triticale seeds. Int. Agrophys. 16, 227–230.

Velten S., Leventon J., Jager N., Newig J., 2015. What is sustainable agriculture? A systematic review. Sustainability 7, 7833–7865. https://doi.org/10.3390/su7067833

Wezel A., Casagrande M., Celette F., Vian J.F., Ferrer A., Peigné J., 2014. Agroecological practices for sustainable agriculture. A review. Agron. Sustain. Dev. 34, 1–20. https://doi.org/10.1007/s13593-013-0180-7

Zarębski Z. W., Dziamba S., 1993. Sposób przedsiewnej obróbki ziarna i urządzenie do przedsiewnej obróbki ziarna [Method of and apparatus for pre-sowing treatment of grain]. Patent RP Nr P.299454.

The source of funding: This research was funded by The University of Life Sciences in Lublin.

Received: 07.06.2022
Accepted: 27.09.2022