Int. Agrophysics, 2009, 23, 229-235

INTERNATIONAL
Agrophysics
www.international-agrophysics.org

Effect of laser and variable magnetic field simulation on amaranth seeds germination

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Received January 21, 2009; accepted April 23, 2009

A b s t r a c t. A study was conducted on the effect of stimulation with He-Ne laser and variable magnetic field on germination of seeds of amaranth cv. Aztek and Rawa at various temperatures. The study involved the use of laser light with power density of $\Phi = 6$ mW cm^{-2}, in five replications, variable magnetic field with induction B = 30 mT and exposure time t = 30 s, and combinations of laser light and variable magnetic field at the above parameters. Amaranth seeds were sown on Petri dishes, at 100 seeds per dish in five replications. The tests were conducted in a controlled climate chamber at temperatures of 10, 12, 15, 20, 25, 35, 45, 55°C, in total darkness. On the basis of the experiments it can be stated that laser stimulation, variable magnetic field, and combinations of the two factors had a favourable effect on the germination of seeds of amaranth, for the applied doses and germination temperatures, but primarily in the initial phase of germination that lasted from several to several dozen hours.

K e y w o r d s: laser and variable magnetic field stimulation, amaranth, germination temperature

INTRODUCTION

Amaranth is one of the oldest crop plants in the world, originating from South America and more and more frequently referred to as the cereal of the 21st Century (Szot, 1999; Szumiło, 2006). Amaranth is classified in class *dicotyledones,* family *Amarantaceae,* genus *Amaranthus.* It comprises approximately 60 species, a vast majority of them being highly troublesome weeds. There is a predominance of annual forms, but some of the species are perennial plants *eg* A. *muricatus,* A. *deflexus.* The height of the particular species varies within the range from 0.3 to more than 3 m (Szot, 1999). It is characterised by high content of proteins, high concentration of fats, fibre, valuable minerals (calcium, phosphor, iron, zinc) and vitamins from groups A, B, C and E, and by the presence of tocotrienols which are inhibitors of synthesis of cholesterol, and of squalenes, and has an extensive range of applications on the industrial scale (Resio *et al*., 2006; Szumiło, 2006; Zapotoczny *et al*., 2006).

The high protein content of seeds of amaranth (15-22%) (Tosi *et al*., 2001; Zapotoczny *et al*., 2006) suggests that protein extracts from its seeds may become a valuable source of dietary proteins. It is also a good source of amino acids – lysine (Resio *et al*., 2006) and methionine (Avanza *et al*., 2005), deficit levels of which are observable in other cereals (Sujak *et al*., 2009). Amaranth is used in the production of food products (Pospišil *et al*., 2006) (groats, gruels, muesli, popcorn, cookies, nuddles, flour as a component of bread, rolls, cakes), animal fodders, cosmetics, medical preparations counteracting the processes of ageing of human organism, and for the protection of surfaces of computer memory discs. It occurs in various climatic zones – from the tropics to moderate areas, and also at various altitudes – from 0 to 3 000 m a.s.l. The period of amaranth vegetation is 160 days. The optimum temperature during vegetation is 26-28°C, and it grows and develops the best within the temperature range of 16 to 35°C (Szot, 1999).

One of the problems involved in amaranth growing lies in its being sensitive to weed infestation, with simultaneous negative effect of most of the active substances contained in herbicides on the growth and development of its plants (Szot, 1999; Szumiło, 2006). Seed quality is the main factor affecting the growth, development and yielding of amaranth plants. Therefore, in amaranth cultures, apart from shortening the period of vegetation, efforts are undertaken to improve the sowing material using a variety of methods. Better and higher crop yields can be obtained through sorting,

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cleaning, drying, and improvement through priming, coating, scarification and stratification of sowing material (Górecki and Grzesiuk, 1994).

For a long time now physical methods have been used to improve the quality of sowing material, including seed irradiation with laser light and stimulation with magnetic or electric field (Dziwulska *et al*., 2004; Koper, 1994; Pietruszewski, 1993; Pietruszewski *et al*., 2002a, 2002b; Rochalska, 2002). Such methods are safe for the natural environment, and they only modify the physiological and biochemical processes in seeds, while increasing their nutritional value. In agricultural production, pre-sowing treatment of seeds with physical factors is gaining in popularity (Dziwulska, 2006; Dziwulska and Koper, 2003; Pietruszewski *et al*., 2007; Sujak *et al*., 2009).

OBJECTIVE OF STUDY

The objective of the study was to estimate the effect of stimulation with He-Ne laser light and with variable magnetic field on the germination of seeds of amaranth cv. Aztek and Rawa at various temperatures. The Aztek cultivar originates from South America and was entered in the COBORU register in the year 2000 (2004), while the Polish cv. Rawa was bred in the year 1997 (Szot, 1999).

MATERIAL AND METHODS

At the beginning of the nineteen nineties, at the Faculty of Physics of the University of Natural Sciences in Lublin, three different methods of pre-sowing stimulation of seeds have been developed. For practical implementation of those technologies, apparatus for laser stimulation of crop seeds and vegetable plants was designed (Koper, 1996; Koper and Dygdała, 1993; 1994; Koper and Woźniak, 1995), the basic element of which is the He-Ne laser (Halliday *et al*., 2005).

In this study was employed a technology known as the divergent beam method, using a He-Ne laser with relative power of 40 mW. The seeds were placed in the feed container of the apparatus, and they were irradiated with He-Ne laser light during their free descent down the vibration trough. The trough is provided with adjustment of slope angle and vibration frequency, which permits control of the speed of move- ment of the layer of irradiated seeds.

The study involved the use of laser light with power density of $\Phi = 6$ mW cm^{-2}, in five replications, variable magnetic field with induction B = 30 mT and exposure time t = 30 s, and combinations of laser light and variable magnetic field at the above parameters. The stimulation of seeds was conducted using test apparatuses: for the stimulation with laser light – the apparatus designed by Koper and Dygdała (1993 and 1994), and for the stimulation with variable magnetic field by means of an electromagnet – a system designed by Pietruszewski (1993).

The germination capacity of seeds was determined in the laboratory experiment. Amaranth seeds were sown on Petri dishes, at 100 seeds per dish, in five replications. The tests were conducted in a controlled-climate chamber, at temperatures of 10, 12, 15, 20, 25, 35, 45, and 55°C, in total darkness.

RESULTS AND DISCUSSION

Designation of the germination capacity of different seed species the optimal, minimal and maximal temperatures are used, although the optimal temperature does not warrant the highest germination capacity (Ciupak *et al*., 2007). Amaranth seeds grown in the soil at the temperature of 10°C usually germinate after 4 to 5 days, however the higher temperature is required for the growth of the plants. The temperature optimal for the germination of the amaranth seeds was estimated as 25°C (Szot, 1999). In the case of the seeds of tomatoes and capsicum the maximal germination capacity was observed at 20 and 25°C, respectively, what was also observed by Podleśny (2002) for the seeds of white lupin.

Figures 1-3 present the relative kinetics of germination of amaranth seeds of both of the studied cultivars, stimulated with laser light and variable magnetic field, in the function of time, at various temperatures. The relative kinetics is expressed as a number giving the ratio of the number of germinated seeds subjected to stimulation to the number of seeds germinated in the control sample for a given time. Figure 4 presents the germination capacity of amaranth seeds with relation to temperature, for stimulated seeds and for the control.

Stimulation of seeds of amaranth cv. Rawa with variable magnetic field gave a positive effect on the germination kinetics in the initial phase (lasting *ca*. 10-12 h) for the temperature of 55°C, and within a time interval of up to *ca*. 80 h for the temperature of 12°C (Fig. 1a). Seeds of amaranth cv. Aztek were also favourably affected by variable magnetic field during the initial period of germination at low temperatures of 10 and 15°C, as well as at room temperature and higher - 25, 35, 45, and 55°C (Fig. 1b).

Laser stimulation of seeds of amaranth cv. Rawa, in the initial phase of germination, had a favourable effect for the low temperatures of 12 and 15°C, and for temperatures of 35 and 55°C (Fig. 2a). In the case of amaranth seeds cv. Aztek, in the initial phase of germination, the effect of laser light stimulation was favourable for temperatures of 10 and 15, and for 35, and 55°C (Fig. 2b). A favourable effect of the stimulation on the germination of those seeds was also observed within the time range of up to *ca.* 80 h, for the temperature of 12°C .

Ciupak *et al*. (2007) conducted experiments concerning the influence of laser He-Ne light, magnetic field and both of these factors on the process of germination of buckwead cv.

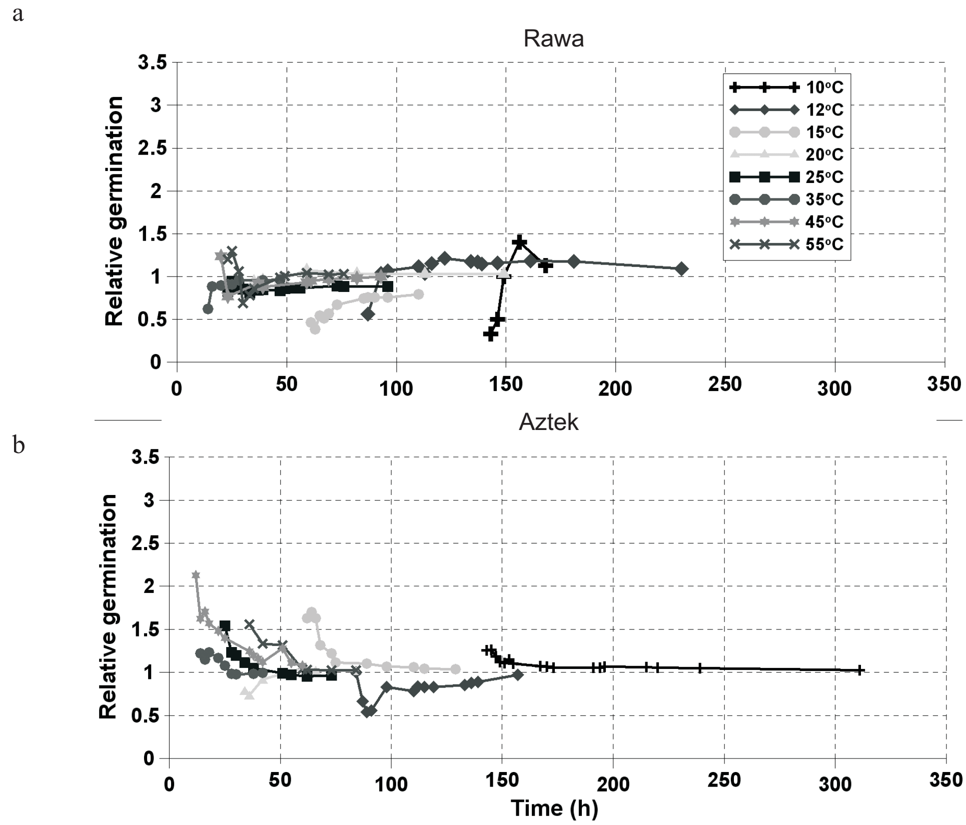

Fig. 1. Relative kinetics of germination of amaranth seeds: a – cv. Rawa, b – Aztek stimulated with variable magnetic field.

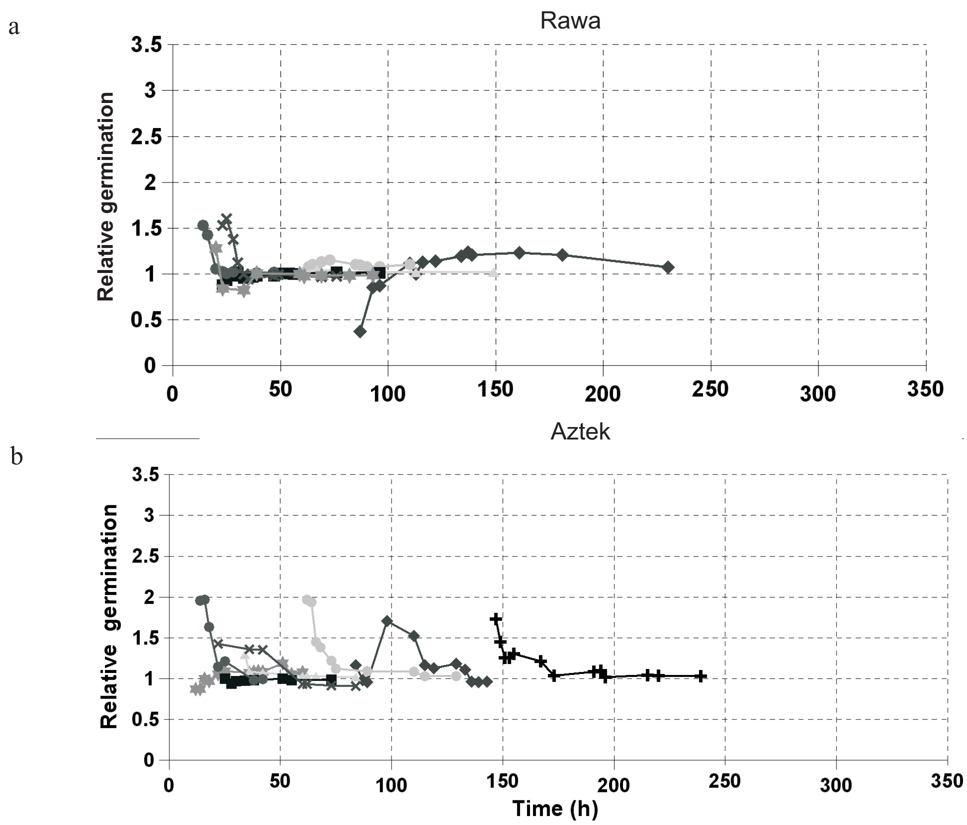

Fig. 2. Relative kinetics of germination of amaranth seeds: a – cv. Rawa, b – Aztek stimulated with laser light. Explanations as on Fig. 1.

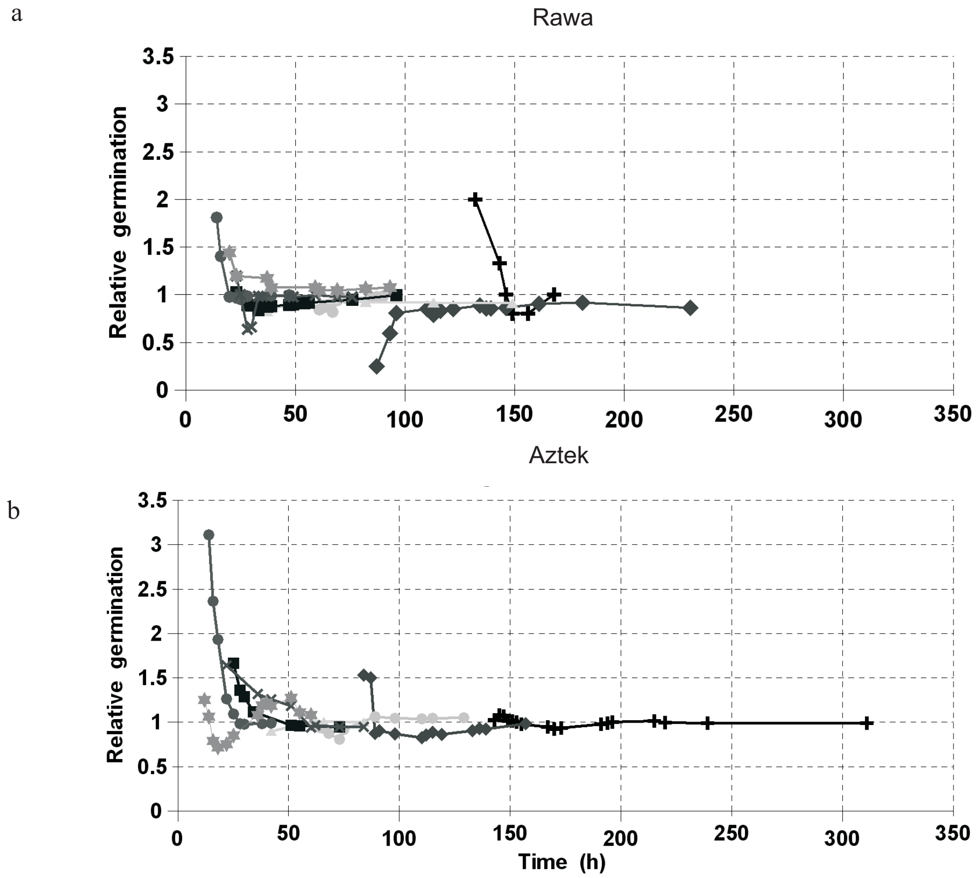

Fig. 3. Relative kinetics of germination of amaranth seeds: a – cv. Rawa, b – Aztek stimulated with magnetic field and laser light. Explanations as on Fig. 1.

Kora at a defined temperature of 21°C. As was shown these physical factors had an effect exclusively on the germination velocity in the initial stage (48 h after sowing). Podleśny (2002) showed that the number of germinating seeds of the white lupin differed already after 24 h past sowing but the highest differences in the germination dynamics have been found during the period of 48 to 96 h past sowing.

Simultaneous stimulation with magnetic field and laser light had a favourable effect on germination of seeds of amaranth cv. Rawa in the initial phase of germination, for the temperature of 10 and for 35 and 45°C, as presented in Fig. 3a. For seeds of amaranth cv. Aztek, magnetic field and laser stimulation effect on germination in the initial phase was positive at temperatures of 12, 25, 35, and 55°C (Fig. 3b).

The kinetics of germination of seeds of amaranth of both cultivars, for all types of stimulation and for the control samples, was the highest at temperatures of *ca.* 20 and 42°C, and the lowest at temperature of 10°C, which is presented in Fig. 4.

Tables 1 and 2 present the germination capacity of amaranth seeds of both cultivars at various temperatures. Analysis of results of the study with a level of statistical significance was conducted by means of the Tukey test for seed germination capacity.

For the estimation of the effect of stimulation with selected factors the authors used also the coefficient of variation, expressed in percentages, that is the ratio of standard deviation and the value of mean germination capacity of stimulated seeds germinating at a specific temperature. The coefficient of variation is a measure of differentiation in the distribution of a trait and defines its absolute variation *ie* it is a relative measure that depends on the value of the arithmetic mean. The coefficient of variation was the highest for samples of seeds of amaranth cv. Rawa germinating at low (10, 12 and 15°C) and high (45 and 55°C) temperatures for all samples of stimulated seeds and for the control. In the case of seeds of amaranth cv. Aztek, the highest values of the coefficient were recorded for germination temperatures of 10, 20 and 55°C. The coefficient of variation was also the highest for samples that were not statistically significant, for which a positive effect of stimulation was obtained for the initial phase of germination and which achieved germination capacity that differed only slightly from that of the control samples.

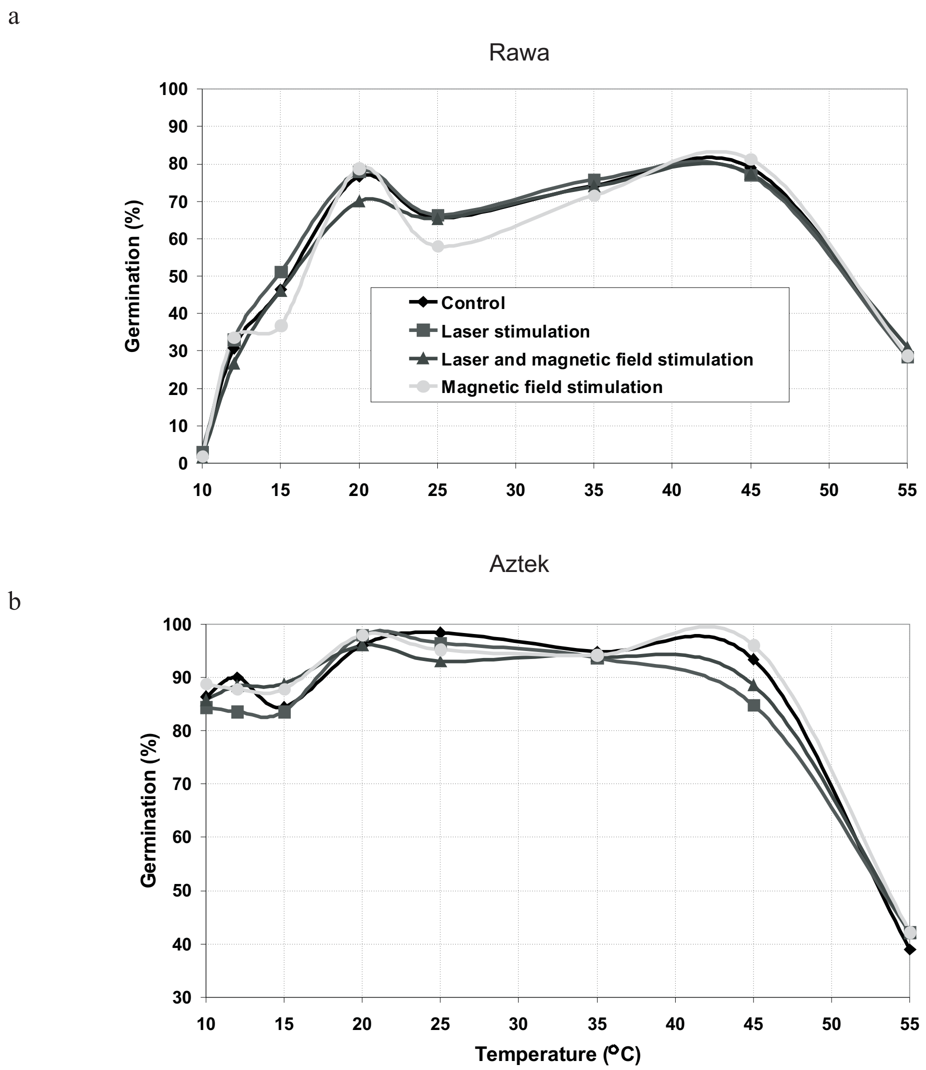

Fig. 4. Germination kinetics of amaranth seeds: a – cv. Rawa, b – Aztek stimulated with magnetic field, laser light, and magnetic field and laser light, in the function of temperature.

T a b l e 1. Germination capacity of amaranth seeds cv. Rawa at various temperatures

Temperature (°C)	Control	Laser stimulation	Laser and magnetic field stimulation	Magnetic field stimulation
10	29.6 ± 2.4 (8.21)	34.6 ± 2.2b (6.31)	23.4 ± 2.0c (8.66)	28.2 ± 2.4d (8.46)
12	30.8 ± 3.3 (10.81)	33.0 ± 3.3b (10.06)	26.6 ± 1.2c (4.51)	33.6 ± 2.7d (7.93)
15	46.4 ± 2.0 (4.26)	51.2 ± 1.4b (2.83)	46.2 ± 4.4c (9.61)	36.8 ± 3.0d (8.28)
20	78.0 ± 0.8 (0.99)	76.5 ± 1.8b (2.33)	**78.8 ± 1.5cd** (1.95)	**70.0 ± 1.5dac** (2.18)
25	65.6 ± 3.0 (4.63)	96.4 ± 0.9b (0.95)	**93.0 ± 1.1ca** (1.24)	95.2 ± 1.2d (1.28)
35	94.8 ± 0.16 (0.17)	93.6 ± 1.5b (1.60)	94.0 ± 1.1c (1.13)	94.2 ± 1.2d (1.30)
45	93.4 ± 1.2 (1.28)	84.8 ± 4.2b (4.95)	88.6 ± 2.7c (2.79)	96.0 ± 0.8d (0.85)
55	39.0 ± 2.2 (5.67)	48.0 ± 2.6b (5.52)	44.2 ± 2.7c (6.04)	42.2 ± 1.7d (3.93)

± standard deviation. Mean values in the same column marked with different letters, a-d, differ at statistically significant level of $p \le 0.05$ (bold type). Values of coefficient of variation are given in parentheses.

Table 2. Germination capacity of amaranth seeds cv. Aztek at various temperatures

Temperature (°C)	Control	Laser stimulation	Laser and magnetic field stimulation	Magnetic field stimulation
10	86.4 ± 4.3 (4.93)	84.4 ± 3.3b (3.91)	85.8 ± 3.2c (3.73)	88.8 ± 2.7d (2.99)
12	90.0 ± 1.9 (2.31)	83.6 ± 2.1b (2.56)	88.4 ± 3.1c (3.54)	87.8 ± 2.4d (2.72)
15	84.4 ± 0.7 (0.78)	83.6 ± 1.9b (2.26)	88.8 ± 2.5c (2.85)	87.8 ± 0.9d (1.07)
20	88.8 ± 3.1 (3.48)	94.2 ± 1.6b (1.70)	81.6 ± 4.4c (5.43)	74.0 ± 6.7d (9.08)
25	98.4 ± 0.3 (0.33)	96.4 ± 0.8b (0.87)	**93.0 ± 1.1ca** (1.24)	95.2 ± 1.2d (1.28)
35	94.8 ± 0.4 (0.42)	93.6 ± 1.5b (1.60)	94.0 ± 1.1c (1.20)	94.2 ± 1.2d (1.30)
45	93.4 ± 1.2 (1.28)	84.8 ± 4.1b (4.89)	88.6 ± 2.7c (3.09)	96.0 ± 0.5d (0.54)
55	39.0 ± 2.2 (5.66)	42.2 ± 1.2b (2.83)	44.2 ± 2.6c (5.94)	42.2 ± 1.7d (3.93)

Explanations as in Table 1.

CONCLUSIONS

1. Based on the study presented herein we can state that laser stimulation, variable magnetic field, and combination of those factors had a positive effect on the process of germination of amaranth seeds for the selected doses and germination temperatures, but mainly in the initial phase of germination that lasted from several to several dozen hours.

2. Analysis of results with statistical significance level, performed by means of the Tukey test, that was concerned with the germination capacity alone, revealed significance for only several selected samples germinating at temperatures of 20 and 25°C (Rawa and Aztek – magnetic field and laser stimulation for 25°C, Rawa – magnetic field stimulation for 20°C).

3. Seed stimulation with the physical factors applied in this study had practically no effect on the germination capacity, which probable resulted from the fact that the study was conducted under laboratory conditions.

4. Studies on the effect of laser light and magnetic field stimulation of amaranth seeds should be continued under field conditions, due to the significant effect of those factors in the initial phase, which may have a bearing on further growth and development of plants and on the level of yielding.

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