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Evaluation of the effect of electromagnetic treatment on the sowing qualities of triticale seeds

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Abstract

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The fact of applying energy stimulation is an excellent opportunity to search for alternative environmentally friendly methods and technologies to increase the yields of main crops.

Pre-sowing electromagnetic treatment of triticale seeds of the cultivar Boomerang was performed according to a three-factor experiment and the symmetrical composition plan B3. The controllable factors of the treatment used, were voltage or tension (U), kilovolts (kV) between electrodes of the treatment device, exposure time (τ) in seconds and duration (T) in days of seed pre-treatment before sowing in laboratory conditions.

In order to determine the optimal growth environment, which would lead to an overall positive impact on seed performance, a mathematical processing of the results obtained was carried out and mathematical models of all observed variables were built. Based on these, their corresponding surfaces and lines of response were compiled, and by using them, the optimal limits of the controllable factors for maximum stimulation of the sowing qualities of the pre-sowing treated seeds, were determined.

Based on the determined levels of controllable factors of pre-sowing electromagnetic treatment, studied variables were stimulated: germinating vigor up to 3.0% and germination up to 6.0%, number of roots up to 9.4%, root length up to 33.0%, sprout length up to 7.6%, and fresh and dry masses up to 35.6% and 37.0%, respectively.

The proposed electromagnetic treatment of triticale seeds could be applied both in conventional and organic farming to improve the seed sowing qualities and subsequently to accelerate the growth and development of plants and increase the yield.

Key words: electromagnetic treatment; triticale; germination; primary root system; response

Introduction

The growing needs for feeding people and animals has forced humanity to focus on cereals, such as the artificial hybrid between wheat and rye called triticale. This hybrid combines the high productive potential and good quality of wheat with the reduced requirements of rye, as regards soil conditions and weeds, as well as flexibility for weather conditions (Oettler, 2005; Beres et al., 2010; Goyal et al., 2011). It is used for animal feeding, but increasingly finds application in the bread culture – for production mainly of dietetic food. Triticale growing areas are tending to steadily increase in all corners of the world, especially in Europe (FAOSTAT, 2017).

Very high productive capacity was found for the cultivar Boomerang, as a result of a more sustainable response to stressful growing conditions (Baychev, 2012).

Modern agriculture is geared towards the development and implementation of environmental friendly technologies.

In that context, it is natural desire of researchers to seek opportunities to increase yields of main agricultural crops so that the soil and resulting production is not polluted with over-use of artificial fertilizers.

Up until now, the physical stimulation in pre-sowing treatments with the use of magnetic fields are the most studied. The positive results in seed sowing properties of peas (Iqbal et al., 2012a, b), soybean (Radhakrishnan, 2012), cotton (Bilalis et al., 2013), triticale (Florez et al., 2014) and other cereals (Martinez et al., 2017), and many more, are widely known.

In the analysis performed by Pietruszewski & Martínez (2015) and Martinez et al. (2017) the use of magnetic fields to improve the quality of sowing material was also demonstrated.

The next challenge in this field was the use of pulsed magnetic and electromagnetic fields to stimulate the germination and yield of soybean seeds (Radhakrishnan & Kumari, 2012; Đukić et al., 2017). Such seed treatment, however, requires the development of specialized arrangements, which is a disadvantage.

The authors' own research (Palov et al., 2013) showed that after pre-sowing electromagnetic treatment (with a frequency of 50 Hz) of pea seeds, the germination rate was increased by 2.6%, the sprout length by 5.5%, the root length by 18.6% and the vegetable mass as a whole by 6.9%, compared to the control.

The use of pulsed electromagnetic fields led to the stimulation of maize seeds (Bilalis, 2012b; Aguilar et al., 2015), and maize and tomatoes seeds under Mediterranean conditions (Bilalis et al., 2013), and many others.

It was found that stimulation caused by electromagnetic fields leads to structural changes of the water content in the cell, which has a beneficial role on plants (Radhakrishnan & Kumari, 2012). In this way, seed germination, early plant growth, and yield were improved (Bilalis et al., 2012a).

The use of pulsed electromagnetic fields was also effective in the treatment of fat-rich seeds. Thus, the germination of cotton seeds was increased, the plant growth in the early stage was accelerated (Bilalis et al., 2012c), and the accumulation of chemical elements was also improved (Bilalis et al., 2013). Similar results were obtained from other authors, besides increasing yields, i.e. an earlier maturation of cotton (Stoilova et al., 2011).

Aguilar et al. (2015) compared the effects of germination and growth of maize seeds after treatment with magnetic, electric, and electromagnetic fields. After analysis of seed germination, growth dynamics, chlorophyll a, chlorophyll b band total chlorophyll content, as well as the accumulation of fresh mass and dry biomass in plants, they found that the best results were obtained from seeds treated with electromagnetic fields. Moreover, these results have shown values double that of most of the studied parameters.

From the analysis of the reported results, it can be seen that, regardless of the magnetic field source used in the pre-sowing treatments, the researchers' attention was focused on optimizing the controllable factors: field strength, exposure time, etc.

The joint work of the studies in the Rousse University "A. Kunchev" and the Politécnica de Madrid Universities and the Field Crops Institute in Chirpan showed one type of beneficial impact on Triticale seeds. For this purpose, the effects of pre-sowing electromagnetic treatment performed with the specialized modified screw device proposed by Terziev et al. (1994) were studied on seeds of three new Bulgarian Triticale cultivars: Boomerang, Colorit, and Respect.

For pre-sowing seed treatment, electromagnetic, non-magnetic, electrical, etc. fields, were selected because the Earth's field is electromagnetic, and the seeds are *accustomed* to it. For the pre-sowing treatments, electromagnetic field intensities were selected that were many times greater than the Earth's electromagnetic ones.

The preliminary analysis of the results obtained suggests that, comparing to the other two cultivars, the Triticale seeds of the cultivar Boomerang reacted most effectively to pre-sowing electromagnetic treatments.

The aim of this study was based on the mathematical processing of the results obtained in order to find the optimal limits for the controllable factors of electromagnetic treatments that have a stimulating effect on the sowing qualities of the triticale seeds of the Boomerang variety.

Material and Methods

A study was made of laboratory parameters – germinating vigor *g.v.*, laboratory germination *g.*, lengths of roots ℓ_{root}, lengths of sprouts ℓ_{spr}, number of roots N_{root}, fresh mass m_{fresh} and dry mass m_{dry} of the primary root system of Triticale seeds – cultivar Boomerang; the calculated regression equations (Mitkov & Minkov, 1989, 1993) for each parameter and found surfaces and lines of response by means of Statistics 8 software.

M_{fresh} of the primary root system was evaluated after measuring the laboratory parameters. M_{dry} was determined after natural drying, under laboratory conditions, until no change in the mass of primary root system was noted.

Triticale seeds were pre-sowed electromagnetically treated with the specialized modified screw device proposed by Terziev et al. (1994) by applying a three-factor experiment design and by a symmetrical composition plan B3 (Mitkov & Minkov, 1989, 1993).

Controllable factors of treatment such as voltage between electrodes – *U*, kV, exposure duration – τ, s, and duration of stay, *T*, of seeds in days were used until being placed in laboratory conditions for sprouting in a thermostat according to a standard methodology (Sirakov, 2002).

Tension between the electrodes was variable, with a frequency of 50 Hz. This was not in contradiction with the studies conducted by Đukić et al. (2017), where a low frequency (16, 24, 30 and 72 Hz) was used for a duration of 0, 30, 60, and 90 minutes to test the effect of impulse electromagnetic field on germination of soybean seeds and yield. Laboratory studies were performed on 100 seeds in four replicates of 25 seeds each.

The controllable factors, with their values and their levels of variation, are shown in Table 1. These values were consistent with previous ones used in the treatment of wheat (Kostoff et al., 2014).

Triticale seeds of the cultivar Boomerang were electromagnetically treated and were placed in a thermostat to germinate on the 7th, 14th and 21st day, respectively, from the beginning of the treatment.

On the 4th day in the thermostat *g.v.* was recorded, and *g.* on the 7th day.

The results obtained for the studied laboratory parameters were processed to generate the surfaces and lines of their response using the software Statistics 8.

Results

Values of the studied laboratory parameters of the control (without electromagnetic field) seeds are shown in Table 2.

The experimental plan and results obtained in laboratory tests of Triticale seeds treated with electromagnetic field, in percentages relative to the control (%/c), are shown in Table 3.

Table 2. Test results of control (untreated) triticale seeds, the cultivar Boomerang

No.	Studied parameters	Value
1.	Germinating vigor, *g.v.*,%	97
2.	Germination, *g.*, %	90
3.	Number of roots, N_{root}	5.3
4.	Lengths of roots, ℓ_{root}, *mm*	10.2
5.	Lengths of sprouts, $\ell_{spr,}$ *mm*	16.2
6.	Fresh mass, m_{fresh}, *g*	8.0
7.	Dry mass, m_{dry}, g	1.39

The effects ($\hat{Y}_i$, in %/c) of electromagnetic treatments on the observed parameters were obtained. According to the adopted plan of experiment B3 and by methodologies proposed by Mitkov & Minkov (1989, 1993), the calculated models were the following:

$$\hat{Y} = b_0 + b_1\overset{o}{x}_1 + b_2\overset{o}{x}_2 + b_3\overset{o}{x}_3 + b_{12}\overset{o}{x}_1\overset{o}{x}_2 + b_{13}\overset{o}{x}_1\overset{o}{x}_3 + b_{23}\overset{o}{x}_2\overset{o}{x}_3 + b_{11}\overset{o}{x}{}_1^2 + b_{22}\overset{o}{x}{}_2^2 + b_{33}\overset{o}{x}{}_3^2 \quad (1)$$

Equation (1) expresses the dependence of a given parameter (in this case in % relative to the control) from the combination of the individual factors (voltage *U* of treating – factor $\overset{o}{x}_1$, duration τ of exposure – factor $\overset{o}{x}_2$ and duration *T* of stay of seeds from treatment to their planting in laboratory conditions – factor $\overset{o}{x}_3$), and their interactions: $\overset{o}{x}_1\overset{o}{x}_2$, $\overset{o}{x}_1\overset{o}{x}_3$, $\overset{o}{x}_2\overset{o}{x}_3$, $\overset{o}{x}{}_1^2$, $\overset{o}{x}{}_2^2$ and $\overset{o}{x}{}_3^2$.

According to the data in Table 3 the following equations were found:

– For g.v.

$$\hat{Y}_{g.v.} = 102.184 - 0.268\overset{o}{x}_1 - 0.196\overset{o}{x}_2 + 0.124\overset{o}{x}_3 + 0.245\overset{o}{x}_1\overset{o}{x}_2 + 0.425\overset{o}{x}_1\overset{o}{x}_3 + 0.606\overset{o}{x}_2\overset{o}{x}_3 - 0.793\overset{o}{x}{}_1^2 + 0.187\overset{o}{x}{}_2^2 - 0.793\overset{o}{x}{}_3^2 \quad (2)$$

– For g.:

$$\hat{Y}_{g.} = 101.993 - 0.300\overset{o}{x}_1 - 0.300\overset{o}{x}_2 + 0.656\overset{o}{x}_3 + 0.319\overset{o}{x}_1\overset{o}{x}_2 - 0.597\overset{o}{x}_1\overset{o}{x}_3 + 0.319\overset{o}{x}_2\overset{o}{x}_3 + 1.563\overset{o}{x}{}_1^2 - 2.549\overset{o}{x}{}_2^2 + 3.007\overset{o}{x}{}_3^2 \quad (3)$$

Table 1. Controllable factors of pre-sowing electromagnetic treatment of triticale seeds (values and levels of variation)

Controllable impact factors		Levels of change of controllable factors						Factor value for 0.1 division
		High		Average		Low		
Voltage, *U*	$\overset{o}{x}_1$	+1	5kV	0	3kV	-1	1kV	0.2kV
Exposure time, τ	$\overset{o}{x}_2$	+1	50s	0	30s	-1	10s	2s
Stay until sowing, *T*	$\overset{o}{x}_3$	+1	21 days	0	14 days	-1	days	0.7 days

Table 3. Plan of the experiment and results of the laboratory tests after pre-sowing electromagnetic treatment of triticale seeds, the cultivar Boomerang (Germinating vigor (*g.v.*), germination (*g.*), number of roots N_{root}, lengths of roots ℓ_{root}, lengths of sprouts ℓ_{spr} – all data are in percent relative to the control -Table 2 -%/c)

Variant No.	Controllable factors						Results of laboratory tests of Triticale seeds, cultivar Boomerang						
	U		*τ*		*T*		*g.v.*	*g.*	N_{root}	ℓ_{root}	ℓ_{spr}	m_{fresh}	m_{dry}
	$\overset{o}{x}_1$	kV	$\overset{o}{x}_2$	s	$\overset{o}{x}_3$	Days	%/c	%/c	number	*mm*	*mm*	%/c	%/c
1	1	5	1	50	1	21	101.0	103.7	109.4	81.4	104.5	135.6	86.5
2	-1	1	1	50	1	21	101.8	105.9	83.0	88.2	96.5	130.5	98.1
3	1	5	-1	10	1	21	101.0	104.4	101.9	84.3	102.7	129.3	85.8
4	-1	1	-1	10	1	21	100.3	103.7	94.3	87.3	107.6	123.0	94.5
5	1	5	1	50	-1	7	99.7	105.6	10.,8	121.6	105.2	87.9	88.0
6	-1	1	1	50	-1	7	99.7	101.1	100.0	104.9	97.7	81.6	60.6
7	1	5	-1	10	-1	7	99.7	103.3	94.3	133.3	104.5	99.2	77.2
8	-1	1	-1	10	-1	7	103.1	104.4	98.1	111.8	100.8	79.1	72.1
9	1	5	0	30	0	14	101.8	101.1	107.5	80.4	102.7	111.7	137.0
10	-1	1	0	30	0	14	101.0	106.0	100.0	92.2	105.8	120.5	126.9
11	0	3	1	50	0	14	102.4	97.8	103.8	76.5	103.3	87.9	129.8
12	0	3	-1	10	0	14	102.4	101.1	101.9	75.5	101.4	94.1	126.9
13	0	3	0	30	1	21	101.0	106.7	100.0	96.1	104.5	120.5	122.6
14	0	3	0	30	-1	7	101.8	103.3	101.9	92.2	99.0	81.6	124.8

Table 4. Regression coefficients of the equations for: number of roots N_{root}, lengths of roots ℓ_{root} and lengths of sprouts ℓ_{spr} of triticale seeds, the cultivar Boomerang

Studied parameters	b_0	b_1	b_2	b_3	b_{12}	b_{13}	b_{23}	b_{11}	b_{22}	b_{33}	Equation No.
Number of roots – N_{root}	104.717	4.151	0.943	-0.943	3.302	4.245	-1.887	-0.943	-1.887	-3.774	(4)
Lengths of roots – ℓ_{root}	77.390	1.667	-1.961	-12.647	-1.103	-6.050	2.083	8.885	-1.409	16.728	(5)
Lengths of sprouts – ℓ_{spr}	102.951	1.113	-0.990	0.866	2.088	-1.005	-0.851	1.276	-0.580	-1.199	(6)

Based on the regression equations obtained for N_{root}, ℓ_{root} and ℓ_{spr} below, their coefficients are shown in tabular form in Table 4. These coefficients, as well as the coefficients of equations (2) and (3) have been rounded off to the third decimal place.

According to m_{fresh} and m_{dry} data (Table 3) of the formed root system, their regression equations were calculated:

– For m_{fresh}:

$$\hat{Y}_{B.mfresh} = 99.948 + 2.887\overset{o}{x}_1 - 0.126\overset{o}{x}_2 + 20.962\overset{o}{x}_3 - 1.883\overset{o}{x}_1\overset{o}{x}_2 - 1.883\overset{o}{x}_1\overset{o}{x}_3 + 2.824\overset{o}{x}_2\overset{o}{x}_3 + 16.161\overset{o}{x}_1^2 - 8.944\overset{o}{x}_2^2 + 1.098\overset{o}{x}_3^2 \quad (7)$$

– For m_{dry}:

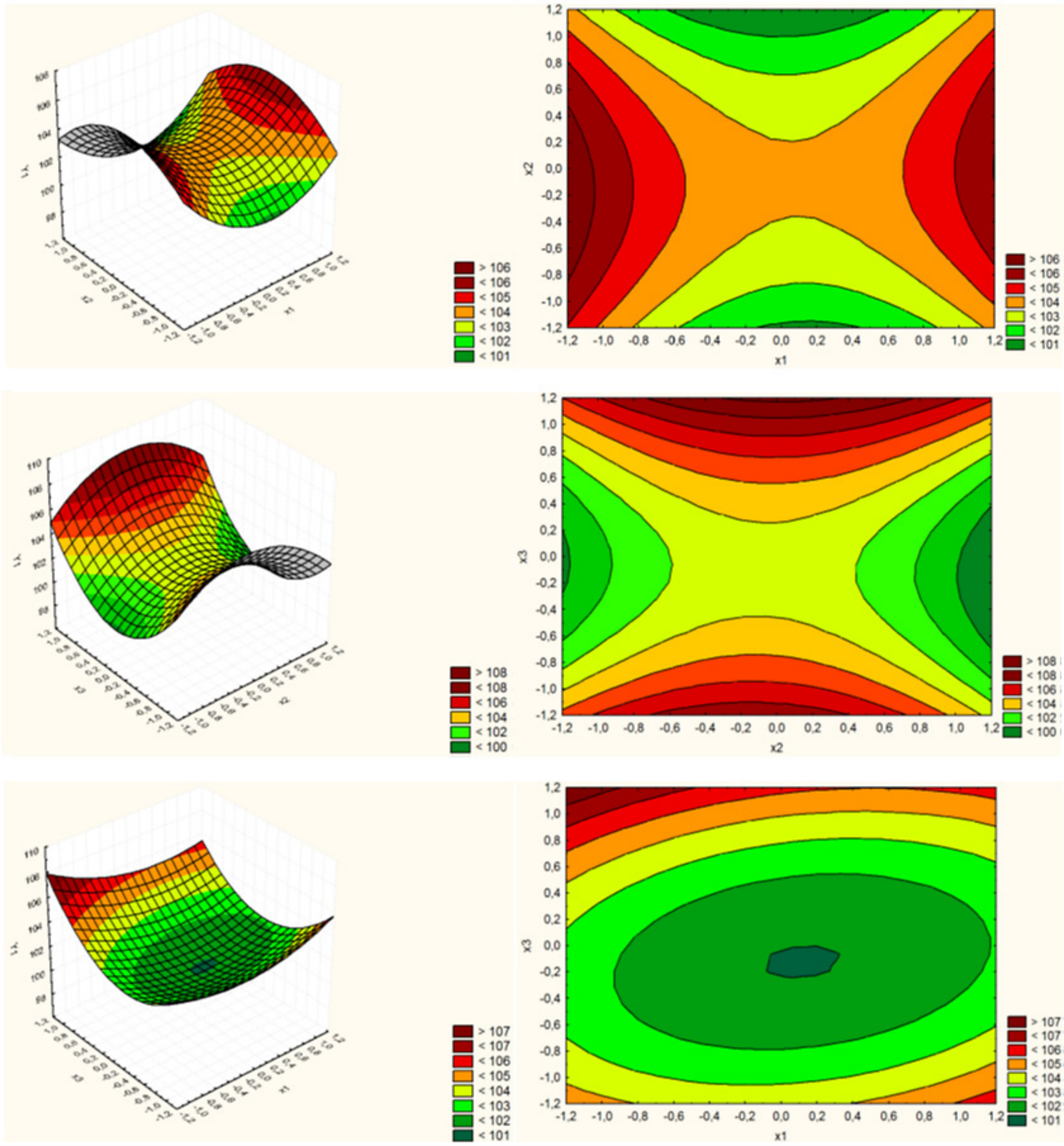
$$\hat{Y}_{B.mdry} = 150.586 + 2.236\overset{o}{x}_1 + 0.649\overset{o}{x}_2 + 6.490\overset{o}{x}_3 + 2.434\overset{o}{x}_1\overset{o}{x}_2 - 6.581\overset{o}{x}_1\overset{o}{x}_3 + 0.631\overset{o}{x}_2\overset{o}{x}_3 - 18.615\overset{o}{x}_1^2 - 22.221\overset{o}{x}_2^2 - 26.908\overset{o}{x}_3^2 \quad (8)$$

Taking into account equations from (2) to (8), and using the software Statistics 8, the surfaces and the lines of response of the respective laboratory parameters were compiled.

Peculiarity was that the surfaces (e.g. in Figure 1a) and lines (e.g. in Figure 1b) of response were constructed after successive exclusion of each of the factors $\overset{o}{x}_1$, $\overset{o}{x}_2$ and $\overset{o}{x}_3$, while the other two factors varied between the proposed levels in Table 1. As the number of controllable factors was three, three surfaces and three lines of response were respectively obtained and analyzed for each observed parameter.

There is a correlation between the quadratic members $\overset{o}{x}_i^2$ of the equation 1. Excluding some of the quadratic members required so that the other coefficients of model (1) had to be recalculated. It should be noted that this recalculation changed not only the values of the free- but also of the non-excluded quadratic members.

Based on that stated above, the coefficients of regression equations from (9) to (29) of the studied laboratory parameters were obtained by sequential exclusion of one of the



case A

case B

case C

a) **b)**

Fig. 1. Surfaces (*a*) and lines (*b*) of response – laboratory germination of triticale seeds, the cultivar Boomerang, at excluded impacts of the factors
Case A – factor (*T*), Case B – factor (*τ*) and Case C – factor (*U*)

controllable factors $\overset{o}{x}_1$, $\overset{o}{x}_2$ and $\overset{o}{x}_3$, and are shown in Table 5.

The found equations (9) to (29) are similar to equation (1).

Figure 1 shows the found surfaces (a) and lines (b) of response of laboratory germination of Boomerang Triticale seeds, respectively, at excluded impact: the factor $\overset{o}{x}_3$ – length of stay T from seed treatment to their planting (case A), the factor $\overset{o}{x}_1$ – tension *U* (case B) and of the factor exposure time $\overset{o}{x}_2$ – τ (case C). The effects of treatment are shown on the right-hand side of the graphs, in color from dark green (lowest impact) to dark red (strongest). The values (in %) of

Table 5. Coefficients of regression equations of the observed laboratory parameters of electromagnetic treated Triticale seeds, the cultivar Boomerang

Studied parameters	Excluded factor	b_0	b_1	b_2	b_3	b_{12}	b_{13}	b_{23}	b_{11}	b_{22}	b_{33}	Equation No.
Germinating vigor *g.v.*	$\overset{o}{x}_3$	101.880	-0.268	-0.196	–	0.245	–	–	0.975	0.004	–	(9)
	$\overset{o}{x}_1$	101.880	–	-0.196	0.124	–	–	0.606	–	0.004	-0.975	(10)
	$\overset{o}{x}_2$	102.256	-0.268	–	0.124	–	0.425	–	-0.749	–	-0.749	(11)
Germination *g.*	$\overset{o}{x}_3$	103.150	-0.300	-0.300	–	0.319	–	–	2.256	-1.855	–	(12)
	$\overset{o}{x}_1$	102.594	–	-0.300	0.656	–	–	0.319	–	-2.188	3.368	(13)
	$\overset{o}{x}_2$	101.013	-0.300	–	0.656	–	-0.597	–	0.974	–	2.419	(14)
Number of roots N_{root}	$\overset{o}{x}_3$	103.266	4.151	0.943	–	3.302	–	–	-1.814	-2.758	–	(15)
	$\overset{o}{x}_1$	104.354	–	0.943	-0.943	–	–	-1.887	–	-2.105	-3.991	(16)
	$\overset{o}{x}_2$	103.991	4.151	–	-0.943	–	4.245	–	-1.379	–	-4.209	(17)
Lengths of roots ℓ_{root}	$\overset{o}{x}_3$	83.824	1.667	-1.961	–	-1.103	–	–	12.745	2.951	–	(18)
	$\overset{o}{x}_1$	80.807	–	-1.961	-12.647	–	–	2.083	–	0.641	18.778	(19)
	$\overset{o}{x}_2$	76.848	1.667	–	-12.647	–	-6.005	–	8.560	–	16.403	(20)
Lengths of sprouts $\ell_{spr.}$	$\overset{o}{x}_3$	102.490	1.113	-0.990	–	2.088	–	–	0.999	-0.857	–	(21)
	$\overset{o}{x}_1$	103.441	–	-0.990	0.866	–	–	-0.851	–	-0.286	-0.904	(22)
	$\overset{o}{x}_2$	102.728	1.113	–	0.866	–	-1.005	–	1.142	–	-1.332	(23)
Fresh mass m_{fresh}	$\overset{o}{x}_3$	100.370	2.887	-0.126	–	1.883	–	–	16.415	-8.690	–	(24)
	$\overset{o}{x}_1$	106.167	–	-0.126	20.962	–	–	2.324	–	0.214	4.828	(25)
	$\overset{o}{x}_2$	96.508	2.887	–	20.962	–	1.883	–	14.097	–	0.966	(26)
Dry mass m_{dry}	$\overset{o}{x}_3$	140.237	2.236	0.649	–	2.434	–	–	24.824	28.430	–	(27)
	$\overset{o}{x}_1$	143.426	–	0.649	6.490	–	–	0.631	–	26.516	-31.204	(28)
	$\overset{o}{x}_2$	142.040	2.236	–	6.490	–	-6.581	–	-23.743	–	-32.036	(29)

the expected impact are also displayed.

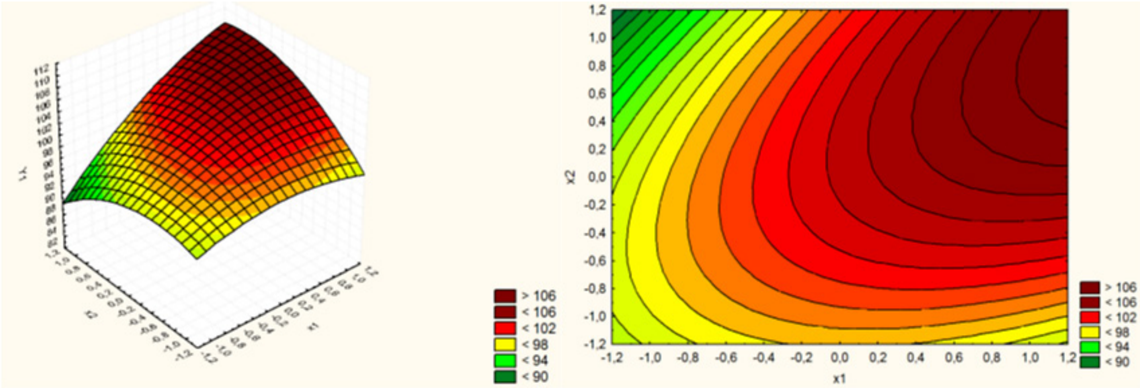
Concerning the obtained laboratory results (Table 3), the compiled equations 4 to 6, the coefficients of which are shown in Table 4, and also with the help of Table 5, the surfaces and lines of response for N_{root}, ℓ_{root} and ℓ_{spr} were obtained.

The surface and lines of response for N_{root}, at excluded impact of the factor $\overset{o}{x}_3$ (*T*, days from treatment to planting) are shown in Figure 2.

Due to the large volume of information in Figure 2 the surface and lines of response, for N_{root} at the exclusion impact of the other two factors: exposure time τ, factor $\overset{o}{x}_2$ – and voltage between electrodes of the device (Terziev et al., 1994) are not shown; however these two cases were analyzed.

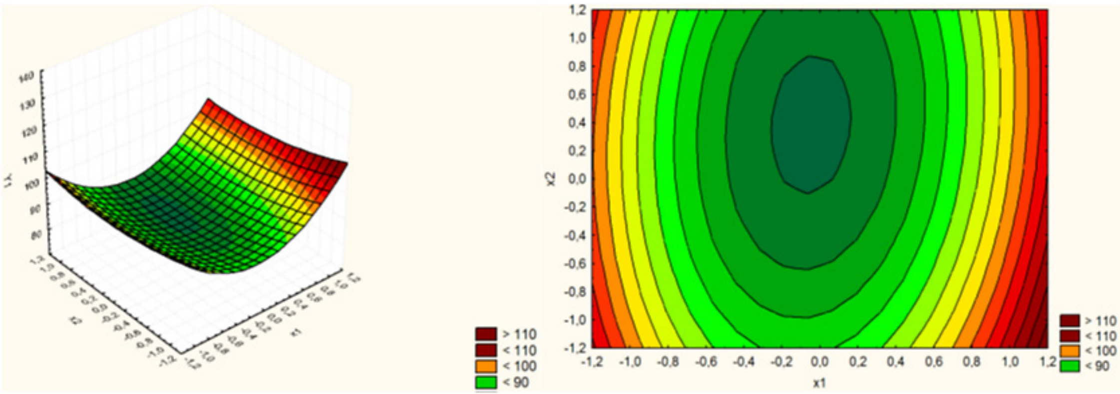
Figure 3 shows the surface and lines of response for ℓ_{root}, at excluded impact of the factor $\overset{o}{x}_3$ (*T*, days of seed stay to their planting).

The areas of controllable factors found, in which the interactions stimulated or suppressed ℓ_{root} of triticale seeds are shown in Table 6.



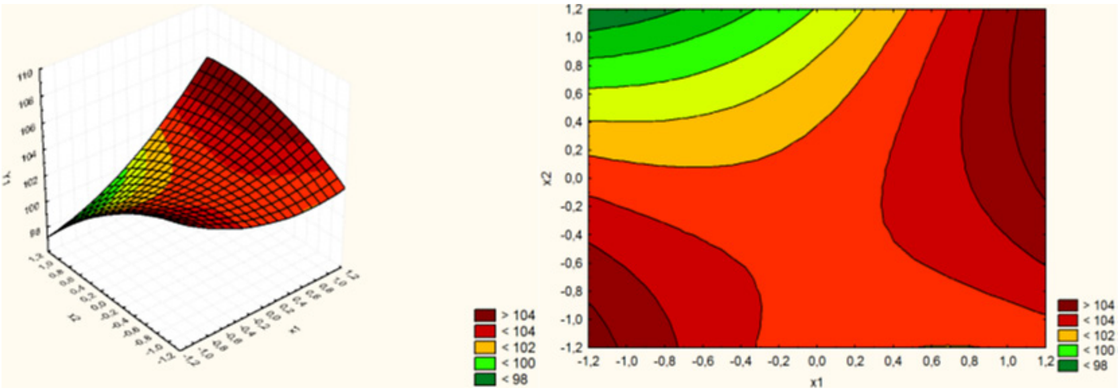
a) **b)**

Fig. 2. Surface *a*) and lines (*b*) of response – number of roots N_{root} of triticale seeds, the cultivar Boomerang – at excluded impact of the factor *T* days of seed stay until their planting



a) **b)**

Fig. 3. Surface *a*) and lines (*b*) of response – lengths of roots ℓ_{root} of triticale seeds, the cultivar Boomerang



a) **b)**

Fig. 4. Surface (*a*) and lines (*b*) of response – lengths of sprouts ℓ_{spr} of triticale seeds, the cultivar Boomerang

Table 6. Zones of the controllable factors, whose interactions stimulate or suppress the lengths of roots ℓ_{root} of triticale seeds, the cultivar Boomerang

Effect $\hat{Y}_{Bi.\ \ell root}$ of the interaction of controllable factors of electromagnetic treatment					
At an average level of factors		Stimulating		Depressing	
$\overset{o}{x}_j$	$\hat{Y}_{Bi.\ \ell root}$, %/к	at $\overset{o}{x}_j$	$\hat{Y}_{Bi.\ \ell root}$, %/к	at $\overset{o}{x}_j$	$\hat{Y}_{Bi.\ \ell root}$, %/к
Case 1 – excluded factor at $\overset{o}{x}_3$					
$\overset{o}{x}_1 = 0$ $\overset{o}{x}_2 = 0$	83,8	$\overset{o}{x}_1 = (1.1 \ldots 1.2)$ $\overset{o}{x}_2 = (-1.1 \ldots -1.2)$	110 over	$\overset{o}{x}_1 = (-0.9 \ldots 0.9)$ $\overset{o}{x}_2 = (-1.2 \ldots 1.2)$	98 below
Case 2 – excluded factor at $\overset{o}{x}_2$					
$\overset{o}{x}_1 = 0$ $\overset{o}{x}_3 = 0$	76,9	$\overset{o}{x}_1 = (0.85 \ldots 1.2)$ $\overset{o}{x}_3 = (-0.9 \ldots -1.2)$	120 over	$\overset{o}{x}_1 = (-1.2 \ldots 1.2)$ $\overset{o}{x}_3 = (-0.7 \ldots 1.2)$	98 below
Case 3 - excluded factor at $\overset{o}{x}_1$					
$\overset{o}{x}_2 = 0$ $\overset{o}{x}_3 = 0$	80,8	$\overset{o}{x}_2 = (-1.2 \ldots 1.2)$ $\overset{o}{x}_3 = (-1.0 \ldots -1.2)$	120 over	$\overset{o}{x}_2 = (-1.2 \ldots 1.2)$ $\overset{o}{x}_3 = (-0.7 \ldots 1.2)$	98 below

Figure 4 shows the surface and lines of response found for ℓ_{spr} at excluded impact of the factor $\overset{o}{x}_3$ (*T*, days of seed stay to their sowing).

Figure 5 shows the images of the obtained surfaces and lines of response for m_{dry} of the primary root system of triticale seeds.

Established values of the controllable factors of the electromagnetic treatment, which favorably affected the observed parameters, are shown in Table 7.

Discussion

The results of the laboratory tests after pre-sowing electromagnetic treatment of the triticale seeds (Table 3) show that the controllable factors having different values had unequal stimulating or suppressing effects on the observed parameters of developing seeds. For example, at variant 8 (U = 1 kV, τ = 10 s and T = 10 days), the laboratory germinating vigor of triticale seeds were stimulated comparing to the control *g.v.* = 103.1%/c. The strongest stimulation was found for the laboratory germination *g.* = 106.7%/cat variant 13, but already with other values of the controllable factors (U = 3kV, τ = 30s and T = 21 days).

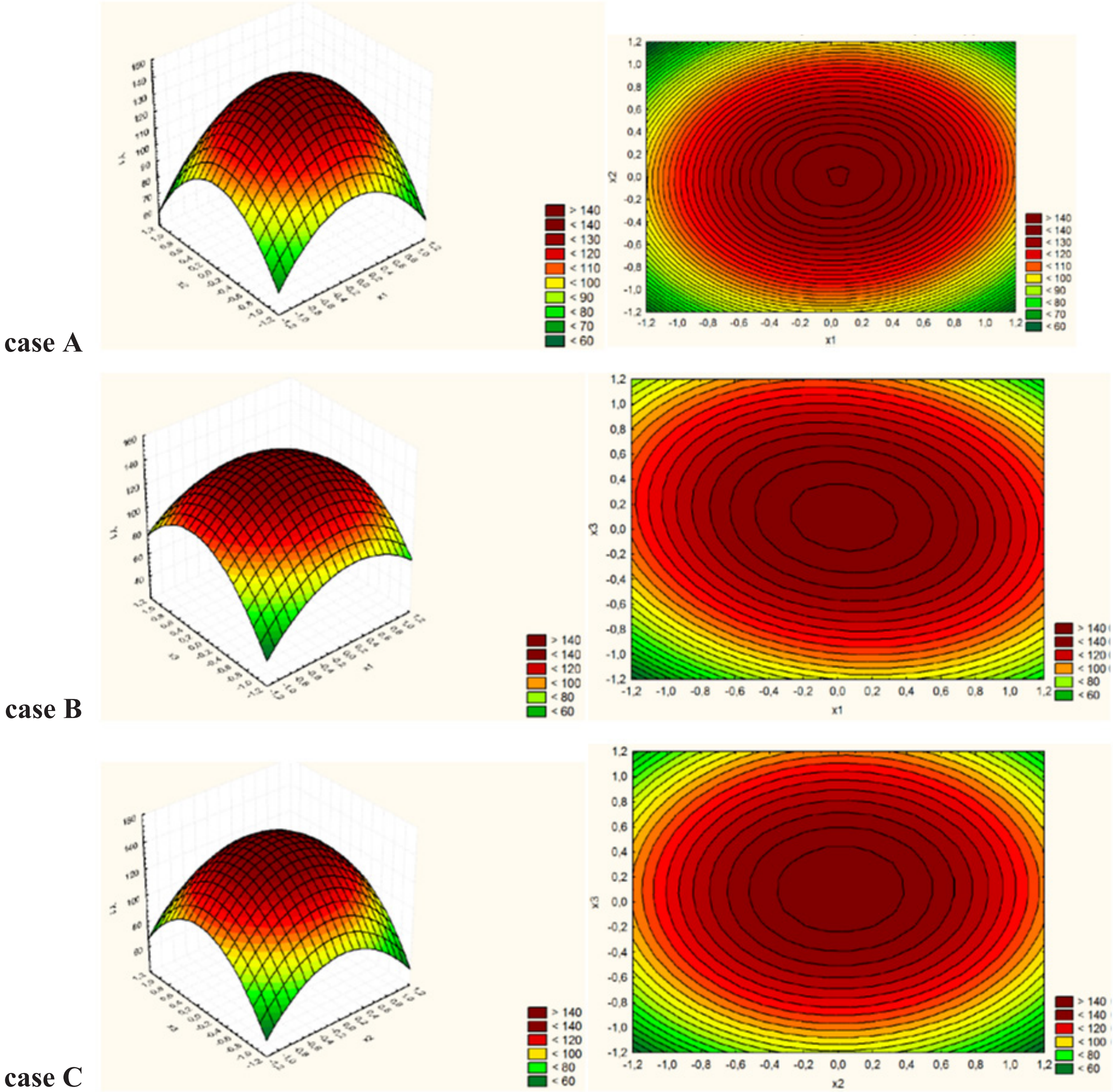
Đukić et al. (2017) also reported that exposure to electric, magnetic and electromagnetic waves showed either positive or negative effects in many studies, influencing germinating vigor, germination, seed weight, plant height, protein content, productivity, leaf surface, fruit weight, and yield. Study results depended on the frequency, duration of exposure, seed traits, and plant species.

From the data of Table 3, it can also be seen that, besides option 11 (U = 3kV, τ = 50s and T = 14 days), where g = 97.8%/c, in all other treatment variants of laboratory germination of Triticale seeds was increased within the limits *g.* = (101.1...106.7) %/c.

The impact of electromagnetic field was not the same on N_{root}, ℓ_{root} and ℓ_{spr} for a particular variant. For example, on variant 1 (U = 5kV, τ = 50s and T = 21 days) N_{root} was stimulated = 109.4%/c, while the lengths of roots and sprouts were unequally suppressed, i.e. they had smaller lengths than controls: ℓ_{root1} = 81.4%/c and ℓ_{spr1} = 96.5%/c.

Other similar differences can also be found, in which the number of roots was less compared to the control, while their lengths and lengths of sprouts were greater.

At variant 5 (U = 3kV, τ = 30s and T = 21 days), an overall positive impact was achieved on the three observed parameters: N_{root} = 103.8%/c, ℓ_{root} = 121.6%/c and ℓ_{spr} = 105.2%/c.



a) **b)**

Fig. 5. Surfaces (a) and lines (b) of response of dry biomass m_{dry} of primary root system of triticale seeds, the cultivar Boomerang, at excluded impacts of the factors
Case A – factor (*T*), Case B – factor (*τ*) and Case C – factor (*U*)

At this 5th variant of treatment *g.v.* = 99.7%/c was slightly suppressed, but the laboratory germination was higher than that of control *g.* = 105.6%/c.

Analysis of the data of m_{fresh} and m_{dry} showed that the short stay of seeds – *T* = 7 days from treatment to their planting in laboratory conditions had a depressing effect. At all variants of impact, the fresh mass was less than that of the control, and was within the range of m_{fresh} = (79.1–99.2) %/c.

Longer stay from treatment to sowing – *T* = (14 and 21) days has been reflected favorably on the accumulated fresh mass. At variant 13 (*U* = 3kV, *τ* = 30 s and *T* = 21 days) m_{fresh} = 120.5%/c. At the prolonged stay of *T* = 21 days, the param-

Table 7. Limits of the values of the controllable factors of electromagnetic treatment of triticale seeds, the cultivar Boomerang, where it was expected to stimulate the observed laboratory parameters

№	Parameters	U, kV	τ, s	T, days
1	Germinating vigor, $g.v.$	(1.5…3.0)	(6…12)	(10…17)
2	Germination, $g.$	(5.2…5.4)	(16…44)	(21…22)
3	Number of roots, N_{root}	(4.5…5.4)	(36…54)	(14…17)
4	Lengths of roots, ℓ_{root}	(5.2…5.4)	(6…8)	(5…7)
5	Lengths of sprouts, ℓ_{spr}	(2.8…5.4)	(22…24)	(14…18)
6	Fresh mass, m_{fresh}	(2.4…5.4)	(30…54)	(10…22)
7	Dry biomass, m_{dry}	(2.4…5.4)	(10…40)	(11…18)

eter was within the range of 123.0 to 135.6 %/c. More accumulated more fresh mass would further favor the improved development of plants.

In the longest and shortest periods, m_{dry} was significantly less than the one of the control plants. For seeds that had a stay of 21 days, m_{dry} was = (85.8...98.1) %/c. The seven-day stay showed even more depressed results, with m_{dry} having values from 60.6 to 88.0 %/c.

The reported small dry masses were at the lower (-1) and upper (+1) values of the controllable factors: U and τ. It turns out that at average (0) values of the controllable factors, the accumulated dry masses were larger than the control ones, so at option 13 (U = 3kV, τ = 30s and T = 21 days) m_{dry} = 122.6%/c and at option 12, respectively (m_{dry} = 120.5%/c).

Analysis made hitherto show that in case of variant 5 (U = 5kV, τ = 50s, T = 7days), after the pre-sowing electromagnetic treatment, an increase in the values of observed seed parameters was achieved, namely: $g.$ = 105.6%/c, N_{root} = 103.8%/c, ℓ_{root} = 121.6%/c and ℓ_{spr} = 105.2%/c. At the same time this 5th variant depressingly affected the accumulation of fresh and dry masses which were: m_{fresh} = 87.9%/c and m_{dry} = 88.0%/c, respectively.

In the above sense, mathematical processing of research data was necessary to establish the change areas of the three controllable factors which would lead to an overall positive impact on the seed sowing qualities. Parsi (2007) also concluded that appropriate combinations were needed to achieve positive effects.

After mathematical treatment of the results obtained for laboratory germination vigor and germination, equations (2) and (3) were obtained.

Analysis of the signs facing the coded values of the three factors $\overset{o}{x}_1$, $\overset{o}{x}_2$ and $\overset{o}{x}_3$, and in equations (2) and (3), showed an equal effect of the electromagnetic field on the seed sowing qualities. It can be seen that to increase $g.v.$ and $g.$, U – between electrodes of the device (Terziev et al., 1994) – factor $\overset{o}{x}_1$ and τ – factor $\overset{o}{x}_2$ should be reduced (the signs in front of these factors are negative) and T – factor $\overset{o}{x}_3$ is needed to increase.

Analysis of the equations (4), (5) and (6), the coefficients of which are given in Table 4 showed that to enhance N_{root}, ℓ_{root} and ℓ_{spr} the voltage U used between electrodes should be increased – the coefficients are positive. The root lengths would go up if τ and T are reduced (the coefficients b_2 and of b_3 equations (4) and (5) are negative).

In the equations (7) and (8) the signs in front of the coded factors are positive. This means that to raise m_{fresh} and m_{dry} is needed to raise the voltage U used for the treatment. In order to increase the m_{fresh} and m_{dry} of the formed root system it is necessary the seeds to stay longer after their treatment – here the coefficients in front of the factor $\overset{o}{x}_3$ are positive and are respectively: +20.962 and +6.490.

According to Fisher's criterion the equations (2) to (8) are adequate and according to Student's criterion have significant values of the controllable factors.

From the analysis of the equations obtained for $g.v.$ (2) and $g.$ (3), N_{root} (4) ℓ_{root} (5), and ℓ_{spr} (6), it can be seen that no unified values of the controllable factors were found. This statement would impact uniquely on the observed parameters.

The surfaces and lines of response of the monitored and examined laboratory parameters were compiled which are shown on Figures 1 and 5.

Appointed surfaces and lines of response allow an assessment of the effect and interaction between the controllable factors affecting: $g.v.$, $g.$, N_{root}, $\ell_{root,}$ ℓ_{spr}, m_{fresh} and m_{dry}.

For the construction of the surfaces and the lines of response of each parameter its equations were calculated by sequentially excluding one of the factors of impact. These equations are shown in Table 5.

The analysis of data from Table 5 showed that the presowing electromagnetic treatments, with the selected controllable factors, acted differently on *g.v.*, *g.*, N_{root}, ℓ_{root}, ℓ_{spr}, m_{fresh} and m_{dry}. This is confirmed by the fact that some of the coefficients are positive, while others are negative.

One important point that has been taken on board assumes that in the equations (9) to (29) all controllable factors were at their average level. Then, after analyzing the values of coefficients b_0, it can be found that the electromagnetic treatment acted stimulating on the observed laboratory parameters.

Table 5 reveals that for ℓ_{root} the values of b_0 coefficients are below 100%. Similar is the situation for m_{fresh} where the factor was excluded. Then b_0 = 96.508%/c, i.e. less than 100%.

Data analysis showed that during the vegetation a significant increase in the m_{dry} in the plants could be expected after pre-sowing electromagnetic treatment of seeds. This can be accounted by the values of the coefficients b_0 in equations (27), (28) and (29). Thus, relative to the control, the interaction of the factors $\overset{o}{x}_1$, $\overset{o}{x}_2$ and $\overset{o}{x}_3$ gave up the following values of coefficient b_0 of equations of dry biomass:

At the interaction $\overset{o}{x}_1\overset{o}{x}_2 - b_0$ = 140.237%/c;

At the interaction $\overset{o}{x}_2\overset{o}{x}_3 - b_0$ = 143.426%/c;

At the interaction $\overset{o}{x}_1\overset{o}{x}_3 - b_0$ = 142.040%/c.

From Table 5 it can be observed that, at average levels of the controllable factors, an increase could be expected in:

– *g.v.* by 1.880 – 2.256 % – equations (9) to (11);

– *g.* by 2.256 – 3.150 % – equations (12) to (14);

– N_{root} by 3.266 – 4.354 % – equations (15) to (17);

– ℓ_{spr} by 2.490 – 441 % – equations (21) to (23).

Because of the large surface area and lines of response for germinating vigor, these are not shown here. Their analysis, however, showed that, in order to increase the germinating vigor by 2%, seeds should be treated at values of the controllable factors within the limits shown in Table 7.

The analysis of the surface and lines of response of N_{root} in Figure 2, at excluded impact of the factor $\overset{o}{x}_3$ (T, days), as well as of the surfaces and lines of response, at excluded impacts of the factors $\overset{o}{x}_2$ (τ, s) and $\overset{o}{x}_1$ (U, kV) – are not shown here, nevertheless it was found that an increase in the number of roots N_{root} up to 6% more than the control could be obtained after pre-sowing electromagnetic treatments with the values of the controllable factors shown in Table 7.

From the data in Table 6 it is possible to find out that, when the equations of the controllable factors had values at the ends of their variation ranges, stimulation of s ℓ_{root} over 120%/c could be achieved.

From Table 6 it was also found that at average levels of the impact factors, ℓ_{root} were only (76.9...83.8) %/c.

Analysis of the data showed that a stimulating impact on ℓ_{root} could be expected in the case of seed treatment with factors having the values shown in Table 7.

Based on the surfaces and lines of response found (Figure 4), some of which are not shown here, it was found that pre-sowing electromagnetic treatments stimulated ℓ_{spr} in a range over (4…5) %.

After the pre-sowing electromagnetic treatments of triticale seeds, the fresh mass and dry biomass of the primary root system was also observed.

From the data in Table 6, it can be found that if the factor $\overset{o}{x}_3 - T$ was at its low level (T = 7 days), then at each variation of the other two factors (variants (5 to 8) in Table 3) the results for m_{fresh} and m_{dry} were lower than those of the control. For these variants of treatment, m_{fresh} was in the range of 79.1 to 99.2 %/c, and m_{dry} = (60.6...88.0) %/c.

The suppression of the accumulation of green mass and dry biomass could be explained by the fact that the 7 day period was short for the carrying out of these transformations in the germ of the individual seed, which were obtained under the impact of the electromagnetic field.

At the same time, the long-term seed stay – 21 days up to sowing (variants 1-4, Table 3), with any variation of the other two factors, has contributed to intensifying processes during growth. For these variants of treatment, m_{fresh} vary from 123.0 to 135.6%/c. For the same variants, however, m_{dry} was significantly less than the control, and was within the range 85.8-98.1%/c. This can be explained by the internal transformations in the seeds after the electromagnetic treatment.

In the case of seed stay of T = 14 days to their sowing, i.e. the factor $\overset{o}{x}_3$ was at its average level, m_{dry} = (126.9...137.0) %/c, regardless of the values of the other two factors.

It can be observed from Table 6 that there will also be an m_{fresh} rise in the cases when the factor $\overset{o}{x}_2$ was at its average level, i.e. (τ = 30s), regardless of the value of the factor $\overset{o}{x}_1$ (U, kV). Thus, at variant 9, where $\overset{o}{x}_1$ = +1 (U = 5kV), m_{fresh} = 111.7%/c, at variant 10 $\overset{o}{x}_1$ = -1 (U = 1kV) – m_{fresh} = 120.5%/c.

At values of the two factors ($\overset{o}{x}_1$ and $\overset{o}{x}_2$) at average levels (0) and $\overset{o}{x}_3$ = +1 (U = 5kV), i.e. option 13 (U = 3kV, τ = 30s and T = 21 days) almost equal growth in m_{fresh} = 120.5%/c and m_{dry} = 122.6%/c was obtained.

Considering the analysis of surfaces and lines of m_{fresh} (not shown here), in Table 7 the limit values of the controllable factors that would contribute to accumulation of m_{fresh} by more than 20% of the control were plotted. This requires a treatment with values of the impact factors U = (2.4…5.4) kV, τ = (30…54) s and T = (10…22) days.

According to Figure 5, it can be seen that pre-sowing electromagnetic seed treatments with the values of the selected controllable factors resulted in the accumulation of more m_{dry} than in the control seeds in almost the entire selected range of factors variation. Moreover, if the impact factors are at their zero levels (Table 1 – levels 0), an increase of the m_{dry} is expected to reach 140%/c.

Data analysis shows that if the controllable impact factors are selected within the range: $\overset{o}{x}_1$ = (-0.7...1.2), i.e. U = (2.4...5.4) kV, $\overset{o}{x}_2$ = (-0,6...0,5), i.e. τ = (10...40)s and $\overset{o}{x}_3$ = (-0.6...0.5), i.e. T = (11…18) days an increase can be expected in dry mass in the range (120…140)%/c.

Table 7 shows that after pre-sowing electromagnetic treatment maximum effects are expected on observed parameters. These limits do not overlap with each other. This is especially true for the impact values that are expected to have a beneficial impact on ℓ_{root}. Except for the large voltage required between electrodes of the device for pre-sowing treatment U = (5.2…5.4) kV, the formation of longer roots is favored by the short-term electromagnetic impact τ = (6…8) s and short stay of seeds until their sowing T = (5…7) days.

From Table 7 it can be found that an overall positive impact on each observed parameter can be expected if the pre-sowing electromagnetic treatment is performed with controllable factors with values that are within the limits:

– Voltage between electrodes U = (5.2…5.4) kV;

– Exposure time τ = (22…24) s;

– Length of seed stay from treatment to sowing T = (14-17) days.

With an appropriate combination of the controllable factors and taking into account the resulting surfaces and lines of response, an opportunity for a complex stimulation was found, varying laboratory parameters: *g.v.* up to 3% and *g.* up to 6%, N_{root} up to 9.4% ℓ_{root} up to 33%, ℓ_{spr} up to 7.6%, m_{fresh} and m_{dry} up to 35.6% and 37%/c, respectively.

The study results depend, however, on the frequency, duration of exposure, seed traits, and plant species (Cruz et al., 2011; Sedighi et al., 2013; Đukić et al., 2017). Isaac et al. (2011) carried out a pre-sowing electromagnetic treatment of maize seeds, San José variety, with different intensities of 0, 2, 4, and 6 mT for 3 minutes and observed an increase in germination percentage, index of vitality (I and II), and root length, by 3, 20, 34, and 23%, respectively, relative to the control. The same authors found that treatment with 4 mT for 3 minutes' exposure time had the best effect on physiological and biometric parameters.

These, and other studies conducted by the authors (Kostoff et al., 2014), showed that in pre-sowing electromagnetic seed treatments, the exposure time can be perceived within a few tens of seconds. However, the analysis of other published materials showed that the pre-sowing magnetic treatments sometimes require a longer time – 15, 30, 45, and more minutes to affect seeds (Bilalis et al., 2013), which prolongs the process and reduces productivity.

For the proposed electromagnetic treatments, a specialized, modified, screw device was used. It is simple, consumes little energy and performs ecologically clean effects that do not contradict the Earth's electromagnetic field.

The proposed method is valuable and it can also be used to improve the sowing properties of already stored seeds (spare seeds) for sowing, and seeds of genetic resources.

Conclusion

Based on the studies on the pre-sowing electromagnetic treatment of triticale seeds, the cultivar Boomerang, by mathematical processing of the results obtained and the resulting surfaces and lines of response of the main laboratory parameters for the seed sowing properties, the optimal values of the controllable factors of impact were found: voltage between electrodes U = 5.2…5.4 kV; exposure time τ = 22…24 s, and length of seed stay from treatment to their sowing T = 14 to 17 days.

As a result of the studies conducted with an appropriate combination of the controllable factors, an opportunity was found to stimulate vary the laboratory parameters: germinating vigor up to 3% and laboratory germination up to 6%; number of roots up to 9.4% and lengths of roots up to 33%; lengths of sprouts up to 7.6%; fresh mass and dry biomass of the primary root system up to 35.6% and 37%, respectively.

The achieved results show that pre-sowing electromagnetic treatments could be used in both conventional farming and organic farming in order to improve sowing qualities of the seed and, subsequently to accelerate the growth and development of plants and to increase yields from the agricultural crops.

References

Aguilar, J. O., Rivero, D. S., Puentes, A. E., Perilla, P. E. V. & Navarro, A. M. S. (2015). Comparison of the effects in the germination and growth of corn seeds (*Zea mays* L.) by exposure to magnetic. *Electrical and Electromagnetic Fields*. *Chem. Eng. Trans*., *43,* 169-174.

Alvarez, J., Carbonell, M. V., Florez, M., Martinez, E. & Campos, A. (2012). Study of 125 mT magnetic treatment on the germination and initial growth of Triticale seeds. In: *Scientific Works of the University of Rousse, Vol. 51, Series 3.1,* Bulgaria, University of Rousse, 163-167.

Baychev, V. (2012). Economic characteristic of the triticale variety

Boomerang. *Field Crops Study, 8 (2),* 261-267 (Bg).

Beres, B. L., Harker, K. N., Clayton, G. W., Blackshaw, R. E. & Graf, R. J. (2010). Weed competitive ability of spring and winter cereals in the Northern Great Plains. *Weed Technol.*, *24,* 108-116.

Bilalis, D. J., Katsenios, N., Efthimiadou, A., Efthimiadis, P. & Karkanis, A. (2012a.) Pulsed electromagnetic fields effect in oregano rooting and vegetative propagation: a potential new organic method. *Soil Plant Sci.*, *62 (1),* 94–99.

Bilalis, D. J., Katsenios, N., Efthimiadou, A. & Karkanis, A. (2012b.) Pulsed electromagnetic field: an organic compatible method to promote plant growth and yield in two corn types. *Electromagn. Biol. Med.*, *31(4),* 333–343.

Bilalis, D., Kamariari, P. E., Karkanis, A., Efthimiadou, A., Zorpas, A. & Kakabouki, I. (2013). Energy inputs output and productivity in organic and conventional maize and tomato production under Mediterranean conditions. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca*, *41(1),* 190–194.

Bilalis, D. J., Katsenios, N., Efthimiadou, A., Karkanis, A. & Efthimiadis, P. (2012c.) Investigation of pulsed electromagnetic field as a novel organic pre-sowing method on germination and initial growth stages of cotton. *Electromagn. Biol. Med.*, *31(2),* 143–150.

Cruz, D. G., Bautista, R. Z., Aguilar, C. H., Pacheco, F. A. D., Orea, A. C. & Bonilla, J. L. L. (2011). Physical characteristics of grain of maize presowing treated by electromagnetic fields. *Acta Agrophysica*, *18 (1),* 17-31.

Đukić**, V., Miladinov, Z., Dozet, G., Cvijanović, M., Tatić, M., Miladinović, J. & Balešević-Tubić, S. V.** (2017). Pulsed electromagnetic field – a cultivation practice used to increase soybean seed germination and yield. *Zemdirbyste-Agriculture*, *104 (4),* 345–352.

FAOSTAT. FAO. (2017). http://www.fao.org/faostat/en/#data/QC. Accessed 10 November 2019.

Flórez, M., Martínez, E., Carbonell, M.V, Álvarez, J. & Campos, A. (2014). Germination and initial growth of Triticale seeds under stationary magnetic treatment. *J. Adv. Agric.*, *2 (2),* 72-79.

Goyal, A., Beres, B. L., Randhawa, H. S., Navabi, A., Salmon, D. F. & Eudes, F. (2011). Yield stability analysis of broadly adaptive Triticale germplasm in southern and central Alberta. *Canada for Industrial End-Use Suitability*. *Can. J. Plant Sci.*, *91*, 125-135.

Iqbal, M., Haq, Z. U., Jamil, Y. & Ahmad, M. R. (2012b.) Effect of pre-sowing magnetic treatment on properties of pea. *Int. Agrophys.*, *26(1),* 25–31.

Iqbal, M., Muhammad, D., Jamil, Y. & Ahmad, M. R. (2012a.) Effect of pre-sowing magnetic field treatment to garden pea (*Pisum sativum* L.) seed on germination and seedling growth. *Pak. J. Bot., 44 (6),* 1851–1856.

Isaac, E. A., Nernandez, C. A., Dominguez, A. P. & Cru, A. O. (2011). Efecto pre-siembra del tratamiento electromagnético sobre la germinación de semillas y el crecimiento de plántulas de maíz (*Zea mays* L.). *Agron. Colomb.*, *29 (2),* 213-220.

Kostoff, K., Palov, I., Sirakov, K., Kuzmanov, E. & Zahariev, S. (2014). Effect of pre-sowing electric treatments of seeds on the yields of wheat varieties Enola and Kristy. *Bulg. J. Agric. Sci.*, *6,* 1526-1530.

Martinez, E., Florez, M. & Carbonell, M. V. (2017). Stimulatory effect of the magnetic treatment on the germination of cereal seeds. *Int. J. Environ. Agric. Biotech.*, *2 (1),* 375-381.

Mitkov, A. & Minkov, D. (1993). I[st] part-1989, II[sd] part-1993. Statistical Methods for Research and Optimization of Agricultural Machinery. Zemizdat, Sofia, 368, (Bg).

Oettler, G. (2005). The fortune of a botanical curiosity Triticale: past, present and future. *J. Agric. Sci.*, *143,* 329-346.

Palov, I., Sirakov, K., Kuzmanov, E. & Zahariev, S. (2013). Results of preliminary laboratory studies after pre-sowing electric treatment of pea seeds. *Agric. Eng.*, *4,* 17-23, (Bg).

Pietruszewski, S. & Martínez, E. (2015). Magnetic field as a method of improving the quality of sowing material*. A review. Int. Agrophys.*, *29,* 377-389.

Radhakrishnan, R. & Kumari, R. B. D. (2012). Pulsed magnetic field: a contemporary approach offers to enhance plant growth and yield of soybean. *Plant Physiol. Biochem.*, *51,* 139–144.

Sedihi, N. T., Abedi, M. & Hosseini, S. E. (2013). Effect of electric field intensity and exposing time on some physiological properties of maize seed. *Eur. J. Exp. Biol.*, *3 (3),* 126-134.

Sirakov, K. (2002). Reasoning of a technological line for cotton delinted (naked) seed. Dissertation, University of Rousse, Bulgaria, (Bg).

Stoilova, A., Palov, I., Sirakov, K. & Radevska, M. (2011). Results obtained from the researches of pre-sowing electromagnetic treatments of seeds of Bulgarian cotton varieties. In: *Ecology, genetics and selection in the service of humanity. Proceedings of the International Scientific Conference June 28-30, Ulyanovski Research Institute for Agriculture, Rossel Academy,* 374-382 (Bg).

Terziev, P., Palov, I., Stefanov, S. & Radev, R. (1994). Patent for invention of Bulgaria No.30631. Device for Pre-Sowing Electrical Treatment of Sowing Material, A 01C 1/00, A01 N 21/00 (Bg).

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