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Study of the effect of pre-sowing electromagnetic impact on the development of primary root system of cotton seeds after different duration of storage. II. Mass of sprout and root

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Abstract

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The effects of pre-sowing electromagnetic treatments of seeds from different crops are the subject of intensive research by many authors such as alternative technologies for ecologically clean agriculture. The aim of this research was to study the effect of pre-sowing electromagnetic treatment on the accumulation of fresh mass of root and sprout of seeds, stored for one and two years before treatment, of five Bulgarian cotton varieties – Chirpan-539, Trakia, Helius, Natalia and Nelina. The seeds of each variety were treated in five electromagnetic fields, with different intensity and duration of exposure. It was found that the selected values of controllable factors had stimulating effect on the mass of sprout, root and total mass of sprout and root of treated seeds. The sprout mass increased by 8.9-13.8%, the root mass – by 6.1–11.3%. The sprout and root total mass increased by 7.8–12.7% and the best treatment options were 1 [U = (8…5) kV, τ = (15…35) s] and 4 [U = (6…3) kV, τ = (5… 25) s]. The two-year period of storage, as a separate factor, determined significantly lower mass of sprout by 8.5%, of root by 10.1% and total mass of sprout and root by 8.9%, compared to the one-year period of storage. Compared to the corresponding untreated control of each storage period, the electromagnetic impact had a stimulating effect in both storage periods: for the mass of sprout – by 11.4-16.8% in options 1 and 5.3-10.4% in options 1 and 4, respectively for one- and two-year storage of seeds; for the root mass – by 5.1-16.1% in options 1 and 4 and by 2.7-8.1% in option 4; for the total mass of sprout and root – by 10.8-16.5% in option 1 and 4.5-9.1% in option 4. Variants with significant higher values than the control variant – Chirpan-539 variety, untreated seeds stored for one year, were reported only for seeds stored for one year. Higher sprout mass was found for Chirpan-539 variety, in option 5 [U = (4…2)kV, τ = (5… 25)s], while higher root mass and sprout and root total mass were found for Nelina variety, in options 1 [U = (8…5)kV, τ = (15…35)s], 2 [U = (6…3)kV, τ = (15…35)s] and 3 [U = (8…5)kV, τ = (5…25)s]. Compared to the corresponding of each variety and storage period untreated control stimulating effect of pre-sowing electromagnetic treatment was observed for all varieties, in both storage periods, except Nelina variety, in this variety positive results were only in one-year storage of seeds. Helius variety reacted most strongly positively to the pre-sowing electromagnetic treatment for the mass of sprout and the total mass of sprout and root of the seeds stored for one year. The total mass of sprout and root increased the most in options 1, 2 and 4 – by 38.6–48.5% compared to the relevant control. Variety Nelina reacted most positively for the mass of root during the one-year storage of seeds, in options 1, 2 and 3.

Keywords: cotton seeds; duration of storage; electromagnetic treatment; sprout mass; root mass; sprout and root total mass

Introduction

Obtaining high yields from agricultural crops is determined by the ability of seeds to germinate, plants to grow together, evenly and stably under different environmental conditions (Savage & Bassel, 2016). The effects of various biochemical (Atanasov et al., 2008; Delibaltova & Kirchev, 2010; Kirchev, 2012) and biophysical methods, including magnetic induction (Alvarez et al., 2019; 2021), laser radiation, electromagnetic waves (Kasakova et al., 2019), etc. used to stimulate seed germination, initial growth and development of plants, and subsequent increase in yields, have been the subject of many studies (Moon & Chung, 2000; Galland & Pazur, 2005; Hernández et al., 2006; Aladjadjiyan, 2007; Hernández et al., 2009; Dominguez et al., 2010).

The effects of pre-sowing treatments of seeds in electromagnetic fields have been intensively studied due to their potential as innovative technologies that can be applied in the conditions of organic farming (Đukić et al., 2017; Ivankov et al., 2021). In recent years, extensive research has been conducted on this issue. Electromagnetic fields have been found to increase germination and improve the early growth characteristics of cotton (Bilalis et al., 2012a). The treatment of cotton seeds before sowing in electromagnetic field has led to almost twice higher yields compared to untreated control seeds (Leelapriya et al., 2003). A number of scientists have reported an increase in germination, length and fresh mass of onion sprout and root (Alexander & Doijode, 1995), corn (Aladjadjiyan, 2002; 2010), barley (Kasakova et al., 2018), rapeseed (Palov et al., 2012), vegetable seeds (Sirakov et al., 2016; Ganeva et al., 2015), rice (Florez et al., 2004), chickpeas (Vashisth & Nagarajan, 2008).

The aim of this research was to study the effect of pre-sowing electromagnetic treatment on the accumulation of fresh mass of root and sprout of cotton seeds stored for one and two years before treatment.

Materials and Methods

Seeds of five cotton varieties Chirpan-539, Helius, Trakia, Natalia and IPK Nelina were the object of the study. Seeds of all varieties were stored for one and two years, after which they were subjected to pre-sowing electromagnetic treatment. The seeds of each variety were treated in 5 different (applied to all varieties) electromagnetic fields with different intensity and duration of exposure. For the purposes of pre-sowing electromagnetic treatments, a method with periodic decrease of the values of voltage U between electrodes of the working camera and increasing the duration of exposure was used (Palov et al., 1995).

Based on previous studies (Palov et al., 1994) a matrix was used to plan the experiment, which is shown in Table 1.

After electromagnetic treatment, the cotton seeds stayed for 23 days. According to Palov et al. (1994) this stay, after treatment until sowing, was necessary so that the seeds can undergo changes that will subsequently favor the development of plants. Some of the seeds of each variety were not treated and served for control, to compare and account the effect of electromagnetic treatment. After the seed treatment and their stay, laboratory experiments were performed. 50 seeds were planted in three replicates of the control and treated variants, for each variety. The seeds of each variant were arranged on filter paper moistened with distilled water on a template. They were rolled and placed in glass baths with distilled water and then set in a thermostat under controlled conditions – temperature 25ºC and humidity 95%. Mass of root and sprout of germinated seeds was measured on the seventh day of their setting into the thermostat. The results for each sample were averaged.

The results were processed by three-way analysis of variance. The ANOVA123 program was used. The factors of experience were: A – Varieties; B – Electromagnetic treatments; C – Periods of storage of seeds before their treatment.

Table 1. Experimental planning matrix for pre-sowing electromagnetic treatment of cotton seeds

Treatment option	Processing steps					
	I		II		III	
	Controllable factors		Controllable factors		Controllable factors	
	U_1 (кV)	τ_1 (s)	U_1 (кV)	τ_1 (s)	U_1 (кV)	τ_1 (s)
1	8	15	6.5	25	5	35
2	6	15	4.5	25	3	35
3	8	5	6.5	15	5	25
4	6	5	4.5	15	3	25
5	4	5	2.5	15	2	25
6	Reference specimen (untreated seeds)					

Chirpan-539 variety (national standard), untreated seeds, one year storage, was accepted as a control variant of the experiment. In addition, electromagnetic treatments were compared to the corresponding untreated controls to each variety and storage period.

Results and Discussion

The results of analysis of variance of studied parameters are presented in Table 2. The interaction of varieties × storage periods (A×C) had the strongest influence on the accumulation of mass of sprout and total mass of sprout and root, the interaction of varieties × treatments (A×B) had the strongest influence on the mass of root. The influence of the three main factors – varieties, treatments and storage periods, was significant for the three studied parameters. Varieties had the most significant share in the overall variation of the three characteristics, while electromagnetic treatments had the least force of influence. The interactions of treatments × storage periods (B×C) and varieties × treatments × storage periods (A×B×C) were insignificant for sprout mass and total mass of sprout and root. Factors affecting the mass of sprout had a stronger effect on the total mass of sprout and root.

Table 3 presents the results of the independent action of the three main factors on the studied parameters. Chirpan-539 variety had the largest mass of sprout and the largest total mass of sprout and root. Trakia variety had the largest root mass, by 13.4% above the standard – Chirpan-539. All varieties, as an independent factor, formed a significant lower sprout mass and lower total sprout and root mass, compared to the standard – Chirpan-539 variety. Natalia variety had a significant lower root mass. The varieties showed specific features for the mass of sprout and root. All pre-sowing electromagnetic treatments, with the exception of option 5, had a significant stimulating effect on the mass of sprout, mass of root and total mass of sprout and root. The sprout mass increased by 8.9–13.8%, the root mass – by 6.1–11.3%, compared to the control variant – untreated seeds. Total mass of sprout and root increased by 7.8–12.7%. Option 1 was best for the mass of sprout and total mass of sprout and root, option 4 – for the mass of root. During the two-year storage, seeds had a lower mass of sprout and root compared to the one-year storage. The longer two-year storage period as a separate factor determined significantly less sprout mass by 8.5%, root mass – by 10.1%, and total sprout and root mass – by 8.9%, compared to the shorter one-year period.

As a result of the varieties × treatments interaction, largest mass of sprout was found for the Chirpan-539 variety in options 1 and 5 – 11.7–12.4% over the control – Chirpan-539, non treated seeds (Table 4). Trakia variety, in options 2 and 4, and Nelina variety, in options 1 and 2, accumulated the largest root mass, exceeding by 21.7–23.5% the control variant. As for the Trakia variety, all treatment variants had a significant larger root mass than the control variant. Chirpan-539 variety showed higher values in option 5 – 14.8%, Helius variety – in options 1 and 4 – 11.3% and 13.9%.

The largest total mass of sprout and root was observed for the variety Chirpan-539, in option 5 – 12.9% above the control. In option 1 the increase was 9.8%. For the variety Helius, in option 1, the total mass of sprout and root was significantly higher by 10.0% of the control, and in option 4 – insignificantly higher by 8.9%. In the other options this parameter was equalized with the control. For the other varieties, the effect of electromagnetic treatments showed alignment with the control variant or significant lower results.

Compared to the corresponding control of each variety, the pre-sowing electromagnetic treatment had the highest positive effect on the seeds of Helius variety (Figure 1). Sprout mass increased in all treatment options, from 19.5%

Table 2. Results of three-factor ANOVA for the mass of sprout, mass of root and total mass of sprout and root after pre-sowing electromagnetic treatment of seeds of 5 cotton varieties after 1 and 2 years storage

Factors	Degree of freedom	Mass of sprout, mm			Mass of root, mm			Total mass of sprout and root, mm		
		Sum of squares	Sum of squares, %	Dispersion	Sum of squares	CSum of squares, %	Dispersion	Sum of squares	Sum of squares, %	Dispersion
A	4	0.130	18.40	22.67***	0.009	14.32	17.0***	0.129	13.65	0.030***
B	5	0.031	4.51	4.44**	0.003	4.69	4.45**	0.047	4.95	0.009***
C	1	0.053	7.50	37.00***	0.006	10.39	49.4***	0.096	10.21	0.096***
A×B	20	0.063	8.82	2.17**	0.011	**18.67**	4.44***	0.098	10.36	0.005**
A×C	4	0.208	**29.38**	36.5***	0.006	10.10	12.0***	0.264	**27.95**	0.065***
B×C	5	0.012	1.65	1.63ns	0.003	4.95	4.71***	0.021	2.21	0.004ns
A×B×C	20	0.039	5.46	1.34ns	0.007	11.44	2.72***	0.061	6.41	0.003ns
Errors	118	0.169	23.95		0.015	24.82		0.228	24.16	0.002

p = 0.05% (*); p = 0.01 (**); p = 0.001 (***)

Table 3. Independent action of factors

Factors		Mass of sprout, mm	In % to the control	Mass of root, mm	In % to the control	Total mass of sprout and root, mm	In % to the control
Varieties	Chirpan-539	0.463	100.0	0.119	100.0	0.582	100.0
	Trakia	0.405	87.5^{000}	0.135	113.4***	0.510	87.6^{000}
	Helius	0.430	92.9^{000}	0.117	98.3	0.547	94.0^{000}
	Natalia	0.395	85.3^{000}	0.114	95.8^{0}	0.509	87.5^{000}
	Nelina	0.388	83.8^{000}	0.125	105.0*	0.513	88.1^{000}
	GD 5.0%	0.018	3.9	0.005	4.2	0.021	3.6
	GD 1%	0.023	5.0	0.007	5.9	0.027	4.6
	GD 0.1%	0.030	6.5	0.009	7.6	0.035	6.0
Treatments	1	0.436	113.8***	0.125	108.7***	0.561	112.7***
	2	0.417	108.9***	0.123	106.9***	0.540	108.4***
	3	0.420	109.7***	0.122	106.1**	0.542	108.8***
	4	0.424	110.7***	0.128	111.3***	0.552	110.8***
	5	0.418	109.1***	0.119	103.5	0.537	107.8***
	6	0.383	100.0	0.115	100.0	0.498	100.0
	GD 5.0%	0.019	5.0	0.006	5.2	0.022	4.4
	GD 1%	0.026	6.8	0.007	6.1	0.030	6.0
	GD 0.1%	0.033	8.6	0.010	8.7	0.038	7.6
Storage terms	1	0.435	100.0	0.129	100.0	0.563	100.0
	2	0.398	91.5^{000}	0.116	89.9^{000}	0.513	91.1^{000}
	GD 5.0%	0.011	2.5	0.003	2.3	0.013	2.3^{000}
	GD 1.0%	0.015	3.4	0.004	3.1	0.017	3.0^{000}
	GD 0.1%	0.019	4.4	0.006	4.7	0.022	3.9^{000}

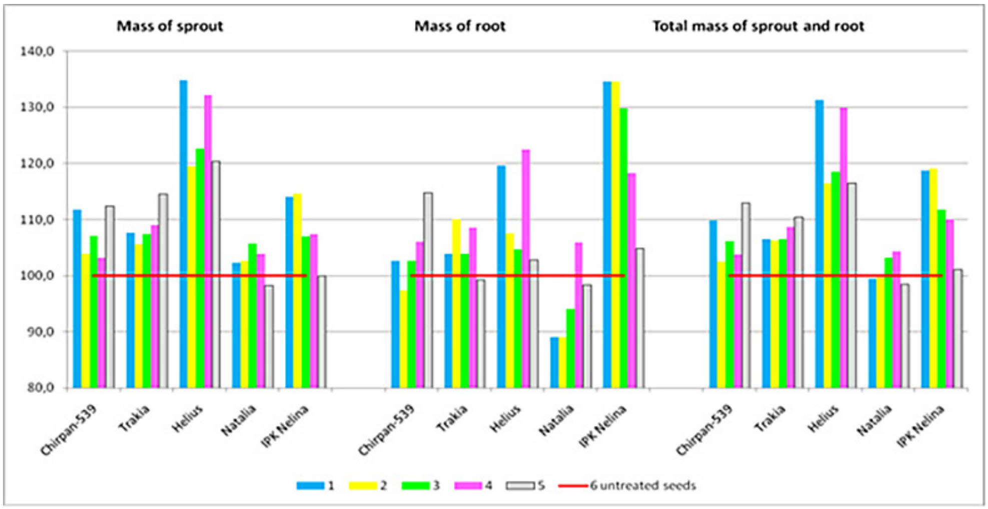


Fig. 1. Effect of pre-sowing electromagnetic treatments on mass of sprout (mm) and mass of root (mm) of seeds of five cotton varieties, in % to the corresponding of each variety untreated control (%/C)

to 34.7%. For the Trakia variety, in option 5, and for the Nelina variety, in option 2, the sprout mass increased by 14.6%. Nelina variety, in options 1, 2 and 3, showed the highest increase in root mass – by 29.8% to 34.6% compared to its relevant control, Helius variety, in option 4 – by 22.4%. The increase in the total mass of sprout and root was strongest expressed for the Helius variety, in options 1 and 4, respectively 31.2% and 29.9%. From the analysis of results, it follows that the varieties reacted specifically to the electromagnetic treatments, depending on their varietal peculiarities.

Table 4. Interaction of factors varieties × treatments (A × B)

Varietis	Treatments	Mass of sprout, mm	In % to control	Mass of root, mm	In % to control	Total mass of sprout and root, mm	In % to the control
Chirpan-539	1	0.486	111.7*	0.118	102.6	0.604	109.8*
	2	0.452	103.9	0.112	97.4	0.564	102.5
	3	0.466	107.1	0.118	102.6	0.584	106.2
	4	0.449	103.2	0.122	106.1	0.571	103.8
	5	0.489	112.4*	0.132	114.8**	0.621	112.9**
	6	0.435	100.0	0.115	100.0	0.550	100.0
Trakia	1	0.406	93.3	0.134	116.5**	0.540	98.2
	2	0.398	91.5	0.142	123.5***	0.539	98.0
	3	0.405	93.1	0.134	116.5**	0.540	98.2
	4	0.411	94.5	0.140	121.7***	0.551	100.7
	5	0.432	99.3	0.128	111.3*	0.560	101.8
	6	0.377	86.7^{00}	0.129	112.2*	0.507	92.2
Helius	1	0.477	109.7	0.128	111.3*	0.605	110.0*
	2	0.423	97.2	0.115	100.0	0.537	94.0
	3	0.434	99.8	0.112	97.4	0.546	99.3
	4	0.468	107.6	0.131	113.9*	0.599	108.9
	5	0.426	97.9	0.110	95.7	0.537	97.6
	6	0.354	81.4^{000}	0.107	92.6	0.461	83.8^{000}
Natalia	1	0.396	91.0	0.106	92.1	0.502	91.3
	2	0.397	91.3	0.106	92.1	0.503	91.5
	3	0.409	94.0	0.112	97.4	0.521	94.7
	4	0.402	92.4	0.126	109.6	0.527	95.8
	5	0.380	87.3^{0}	0.117	101.7	0.497	90.4^{0}
	6	0.387	89.0^{0}	0.119	103.5	0.505	91.8
Nelina	1	0.413	94.9	0.140	121.7***	0.553	100.5
	2	0.415	95.4	0.140	121.7***	0.555	100.9
	3	0.387	89.0^{0}	0.135	117.4**	0.521	94.7
	4	0.389	89.4^{0}	0.123	106.9	0.513	93.3
	5	0.362	83.2^{00}	0.109	94.8	0.471	85.6^{00}
	6	0.362	83.2^{00}	0.104	90.4	0.466	84.7^{00}
GD 5.0%		0.043	9.9	0.013	11.3	0.050	9.1
GD 1.0%		0.057	13.1	0.017	14.8	0.066	12.0
GD 0.1%		0.074	17.0	0.022	19.1	0.086	15.6

As a result of the interaction of varieties × storage periods, all varieties, except Nelina, in one-year storage of seeds, had a lower mass of sprout in both storage periods, compared to the control variant – Chirpan-539, one-year storage of seeds (Table 5). Trakia variety, in one-year storage of seeds, had the highest root mass and exceeded by 16.1% the control variant, followed by Nelina variety – by 13.7%. The varieties reacted differently to the two storage periods. Chirpan-539, Trakia and Helius had the same mass of sprouts during the two storage periods, Natalia – had the same root mass. Natalia and Nelina varieties had a significant lower sprout mass during the two-year storage of seeds, compared to the one-year storage, Chirpan-539, Trakia and Nelina – a significant lower root mass.

Chirpan-539 variety, during the one-year storage of seeds, accumulated the highest sprout and root total mass. The varieties Chirpan-539 and Trakia had a smaller but insignificant total mass of sprout and root during the two-year storage of seeds compared to the one-year storage. The other three varieties, after longer storage of seeds, have been shown to have a lower total sprout and root mass.

The interaction of treatments × storage periods determined higher mass of sprout and root than the control variant (Chirpan-539, one year storage of seeds without treat-

Table 5. Interaction of factors varieties × storage terms (A × C)

Varieties	Storage terms	Mass of sprout, mm	In % to control	Mass of root, mm	In % to control	Total mass of sprout and root, mm	In % to the control
Chirpan-539	1 year	0.465	100.0	0.124	100.0	0.589	100.0
	2 years	0.460	98.9	0.115	92.7^{0}	0.575	97.6
Trakia	1 year	0.399	85.8^{000}	0.144	116.1^{***}	0.543	92.2^{000}
	2 years	0.411	88.4^{000}	0.126	101.6	0.536	91.0^{000}
Helius	1 year	0.420	90.3^{000}	0.119	96.0	0.539	91.5^{000}
	2 years	0.440	94.6^{0}	0.115	92.7^{0}	0.556	81.7^{000}
Natalia	1 year	0.421	90.5^{000}	0.116	93.5^{0}	0.537	78.9^{000}
	2 years	0.369	79.3^{000}	0.113	91.1^{00}	0.481	70.7^{000}
Nelina	1 year	0.467	100.4	0.141	113.7^{***}	0.608	89.3^{000}
	2 years	0.309	66.5^{000}	0.109	87.9^{000}	0.418	61.4^{000}
GD	5.0%	0.025	5.4	0.007	5.6	0.029	4.3
	1.0%	0.033	7.1	0.010	8.1	0.038	5.6
	0.1%	0.043	9.2	0.013	10.5	0.049	7.2

ment) in the one-year storage of seeds (Table 6). All treating options had positive effect, sprout mass increased by 11.4 to 16.8%, the most strongly in option 1. The root mass significantly increased in options 1, 2 and 4 – by 11.0 – 16.1% compared to the control variant. Options 1 and 4 showed the highest positive effects. The total mass of sprout and root was higher by 10.8-16.7%, compared to the control variant – one year of storage, untreated seeds. Option 1 was best for the mass of sprout and for the total mass of sprout and root. During the two-year storage, the treatment options did not show significant differences from the control variant for the mass of sprout and root, respectively for the total mass of sprout and root, which was due to the lower values of the studied parameters, as a result of longer storage of seeds.

For this period of storage, the mass of sprout of treated seeds increased by 5.3% to 10.4%, compared to the corresponding control (Figure 2). The mass of root increased by 7.2% to 8.1%, the total mass of sprout and root – by 4.5 – 9.1%. The increase in the sprout mass and in the sprout and root total mass was the highest in options 1 and 4, in the root mass – in option 4.

As a result of the interaction of the three main factors – varieties × treatments × storage periods, the sprout mass was highest for the variety Chirpan-539, in one-year storage of seeds and options 5, exceeding by 11.0% the control variant – Chirpan-539, untreated seeds, stored for one year (Table 7). The highest root mass was found for Nelina variety, for the seeds stored for one year and options 1,

Table 6. Interaction of factors treatments × storage term (B × C)

Term of storage	Treat-ments	Mass of sprout, mm	In % to control	Mass of root, mm	In % to control	Total mass of sprout and root, mm	In % to the control
1 year	1	0.458	116.8^{***}	0.137	116.1^{***}	0.595	116.7^{***}
	2	0.440	112.2^{***}	0.131	111.0^{**}	0.571	112.0^{***}
	3	0.441	112.5^{***}	0.125	105.9	0.566	110.9^{***}
	4	0.437	111.4^{**}	0.137	116.1^{***}	0.574	112.5^{***}
	5	0.440	112.2^{***}	0.124	105.1	0.565	110.8^{***}
	6	0.392	100.0	0.118	100.0	0.510	100.0
2 years	1	0.413	105.3	0.114	96.6	0.527	103.3
	2	0.394	100.5	0.115	97.5	0.508	99.6
	3	0.399	101.8	0.119	100.8	0.519	101.8
	4	0.410	104.6	0.120	101.7	0.530	103.9
	5	0.395	100.8	0.114	96.6	0.509	99.8
	6	0.374	95.4^{000}	0.111	94.1	0.486	95.3
GD 5.0%		0.027	6.9	0.008	6.8	0.031	6.1
GD 1.0%		0.036	9.2	0.011	9.3	0.042	8.8
GD 0.1%		0.047	12.0	0.014	11.9	0.054	10.6

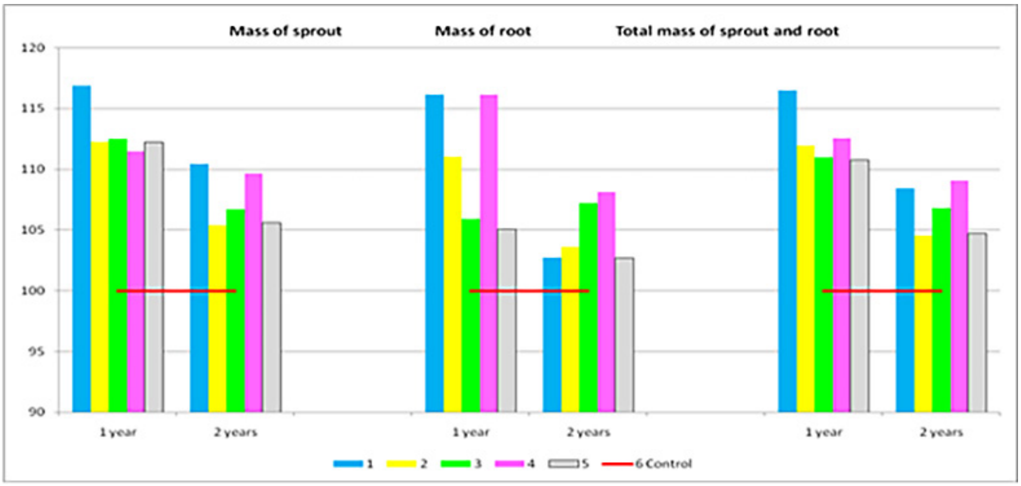


Fig. 2. Effect of pre-sowing electromagnetic treatments on mass of sprout (mm) and mass of root (mm) of seeds stored for one and two years, in % to the corresponding untreated control of each storage period (%/C)

2 and 3 – by 34.5–44.0% above the control variant. For Trakia variety, after one-year storage the seeds, all variants of treatment had a significant higher effect compared to the control variant. In options 2 and 4, the root mass was higher by 31.0–31.9%, in options 1 and 3 – by 21.5–25.9% above the control variant. For Chirpan-539 variety, also after one-year storage of seeds, in options 4 and 5, the root mass was higher by 19.8–22.4% above the control. Variety Nelina had the highest total mass of sprout and root – by 12.3-18.7% above the control variant, in one-year storage of seeds and treating options 1, 2 and 3. Proven higher total mass at the same storage period of seeds was reported for variety Chirpan-539, in options 5 – 13.2%.

Compared to the corresponding controls of each variety and storage period, the highest stimulating effect of pre-sowing electromagnetic treatment was observed for the variety Helius, for seeds stored for one year. This variety reacted most positively for the mass of sprout and for the total mass of sprout and root, and all treating options had a positive effect (Figure 3). The total mass of sprout and root increased the most in options 1, 2 and 4 – by 38.6-48.5%. In the two-year storage of seeds, option 4 was the best – 23.0%. Nelina variety reacted most positively for the mass of root, during one-year storage of seeds and options 1, 2 and 3. For Natalia variety, the pre-sowing electromagnetic treatment had a positive effect only during the one-year storage of seeds. As for the other varieties, a positive effect was found during both storage periods.

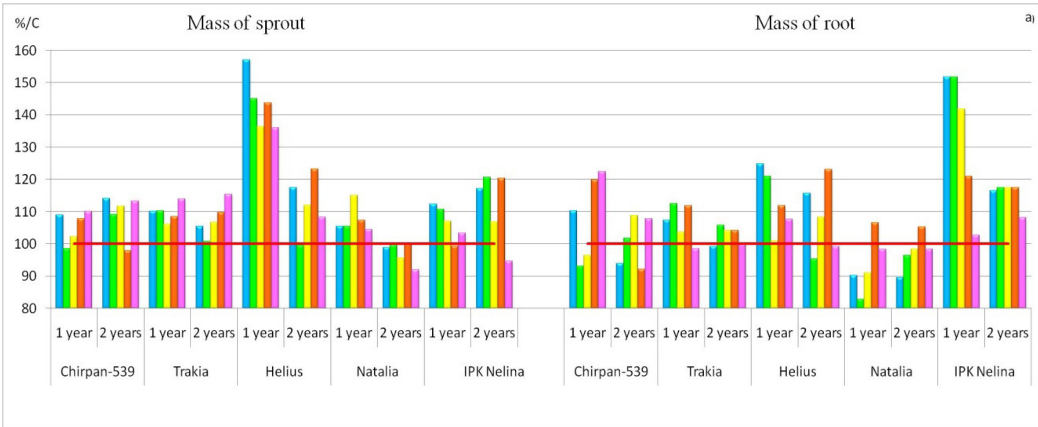
From the above results it was found that the pre-sowing electromagnetic treatment, with the selected values of the controllable factors of impact, had a stimulating effect on the mass of sprout and root of seeds of analyzed 5 cotton varieties. The varieties have reacted specifically to the electromagnetic impact, depending on their varietal characteristics, the physiological state of seeds, the storage periods, etc. Studies to stimulate the germination of wheat, triticale, corn and soybeans showed that the electromagnetic field can be used as a way to improve seed viability (Baluchi, 2004). After pre-sowing electromagnetic treatment (with a voltage frequency of 50 Hz) of pea seeds, the mass of sprout and root as a whole increased by 6.9% compared to the control (Palov et al., 2013a).

The use of pulsed electromagnetic fields improved growth in the early stages of plant development (Bilalis et al., 2012b) and also increased the accumulation of chemical elements in cotton (Bilalis et al., 2013). The parameters of efficient electrical treatments of maize hybrid seeds (U = 1.65kV and t = 10s) (Palov et al., 2013b) and wheat seeds (U = 3kV and t = 35s) were established (Kostov, 2014). Stimulation was achieved of the observed laboratory parameters: germination (g); length of root (l root) and sprout (l sprout); mass of green (m green) and dry (m dry) plants; for seeds of maize hybrids: g = 114.3%/c; l root = 120.6%/c; l sprout = 113.9%/c; m green = 110.5%/c; m dry = 113.7%/c and for wheat seeds: g = 105.3%/c; l root = 102.2%/c; l sprout = 110%/c; m green = 109.3% / c; m dry = 102%/c (Zahariev et al., 2013; Zahariev, 2015). As a result of studies conducted on triticale, Boomerang variety, with an appropriate combination of controllable factors, a possibility of stimulating green and dry masses of plants up to 35.6% and 37.0%, respectively, compared to untreated control, was found (Sirakov et al., 2018; 2021).

Table 7. Interaction of factors varieties × treatments × terms of storage (A × B × C)

Varieties	Years	Treatments	Mass of sprout, mm	In % to control	Mass of root, mm	In % to the control	Total mass of sprout and root, mm	In % to the corresponding control
Chirpan-539	1 year	1	0.484	109.0	0.128	110.3	0.613	109.5
		2	0.438	98.6	0.108	93.1	0.544	97.1
		3	0.454	102.3	0.112	96.5	0.566	101.1
		4	0.479	107.9	0.139	119.8^{*}	0.618	103.3
		5	0.493	111.0^{*}	0.142	122.4^{**}	0.634	113.2^{*}
		6	0.444	100.0	0.116	100.0	0.560	100.0
	2 years	1	0.487	109.7	0.107	92.2	0.594	106.1
		2	0.466	104.9	0.116	100.0	0.583	104.1
		3	0.477	107.4	0.124	106.9	0.601	107.3
		4	0.418	94.1	0.105	90.5	0.523	93.4
		5	0.484	109.0	0.123	106.0	0.607	108.4
		6	0.427	96.2	0.114	98.3	0.541	96.6
Trakia	1 year	1	0.405	91.2	0.146	125.9^{**}	0.551	98.4
		2	0.406	91.4	0.153	131.9^{***}	0.559	99.8
		3	0.399	89.9	0.141	121.5^{**}	0.539	96.3
		4	0.399	89.9	0.152	131.0^{***}	0.551	98.4
		5	0.419	94.4	0.134	115.5^{*}	0.553	98.7
		6	0.368	92.9	0.136	117.2^{*}	0.504	90.0
	2 years	1	0.407	91.7	0.122	105.2	0.529	94.5
		2	0.389	87.6^{0}	0.130	112.1	0.519	92.7
		3	0.412	92.8	0.128	110.3	0.540	96.4
		4	0.424	95.5	0.128	110.3	0.552	98.6
		5	0.445	100.2	0.123	106.0	0.568	101.4
		6	0.386	86.9^{0}	0.123	106.0	0.509	90.9
Helius	1 year	1	0.484	109.0	0.131	112.9	0.615	109.8
		2	0.447	80.8^{00}	0.127	109.5	0.574	102.5
		3	0.420	75.9^{000}	0.106	91.4	0.526	93.9
		4	0.443	80.1^{000}	0.129	111.2	0.572	102.1
		5	0.419	75.8^{000}	0.113	97.4	0.533	95.2
		6	0.308	55.7^{000}	0.105	90.5	0.414	73.9^{000}
	2 years	1	0.470	85.0^{00}	0.125	107.7	0.595	105.3
		2	0.398	72.0^{000}	0.103	88.8	0.501	89.5
		3	0.448	81.0^{000}	0.117	100.9	0.565	100.9
		4	0.493	89.1^{0}	0.133	114.7	0.625	111.6
		5	0.433	78.3^{000}	0.107	92.2	0.541	96.6
		6	0.400	72.3^{000}	0.108	93.1	0.508	90.7
Natalia	1 year	1	0.418	75.6^{000}	0.110	94.8	0.528	94.3
		2	0.418	75.6^{000}	0.101	87.1	0.519	92.5
		3	0.456	82.5^{00}	0.111	95.7	0.568	101.4
		4	0.425	76.9^{000}	0.130	112.1	0.555	99.1
		5	0.414	74.9^{000}	0.120	103.4	0.534	95.3
		6	0.396	71.6^{000}	0.122	105.2	0.518	92.5
	2 years	1	0.373	67.4^{000}	0.103	88.8	0.476	85.0^{0}
		2	0.376	68.0^{000}	0.111	95.7	0.487	87.0^{0}
		3	0.361	65.3^{000}	0.113	97.4	0.474	84.6^{0}
		4	0.378	68.3^{000}	0.121	104.3	0.499	89.1
		5	0.347	62.7^{000}	0.113	97.4	0.460	82.1^{00}
		6	0.377	68.2^{000}	0.115	99.1	0.492	87.9^{0}

Nelina	1 year	1	0.498	90.0	0.167	144.0^{***}	0.665	118.7^{**}
		2	0.491	88.8^{0}	0.167	144.0^{***}	0.658	117.5^{**}
		3	0.474	85.7^{00}	0.156	134.5^{***}	0.629	112.3^{*}
		4	0.440	79.6^{000}	0.133	114.7	0.573	102.3
		5	0.458	82.8^{00}	0.113	97.4	0.571	102.0
		6	0.443	80.1^{000}	0.110	94.8	0.554	98.9
	2 years	1	0.329	59.5^{000}	0.113	97.4	0.441	78.7^{000}
		2	0.339	61.3^{000}	0.114	98.3	0.453	80.9^{00}
		3	0.300	54.2^{000}	0.114	98.3	0.413	73.7^{000}
		4	0.338	61.1^{000}	0.114	98.3	0.452	80.7
		5	0.266	48.1^{000}	0.105	90.5	0.371	66.3^{000}
		6	0.281	50.8^{000}	0.097	83.6^{0}	0.378	66.6^{000}
GD 5.0%			0.061	11.0	0.018	15.5	0.071	12.7
GD 1.0%			0.081	14.6	0.024	20.7	0.094	16.8
GD 0.1%			0.104	18.8	0.031	26.7	0.121	21.6



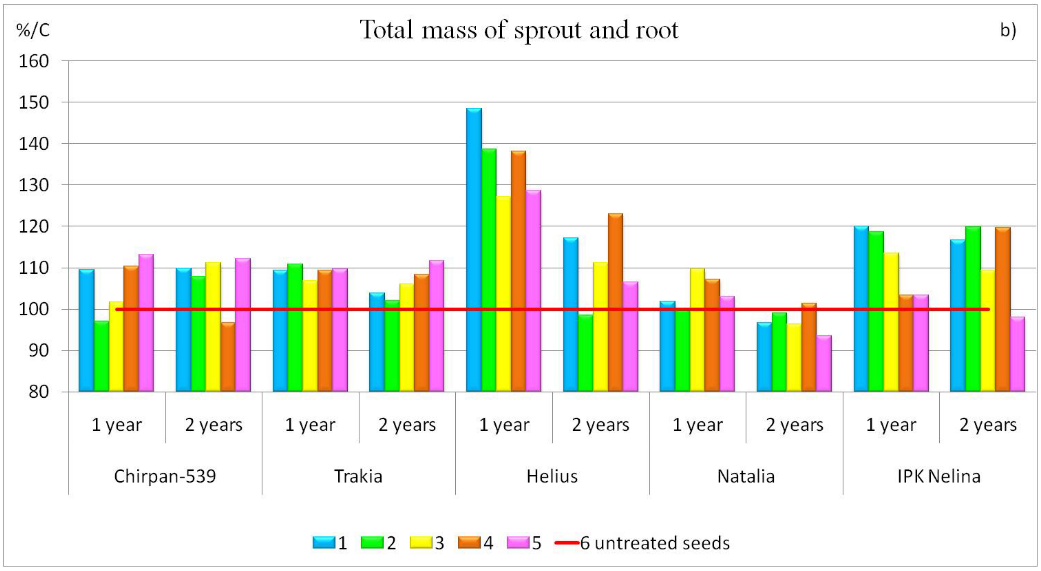


Fig. 3. Effect of pre-sowing electromagnetic treatments on the mass of sprout and mass of root (a), and total mass of sprout and root (b) (mm) of seeds stored for one and two years, in % to the corresponding untreated control (C) of each variety and storage period

The results obtained from this study are comparable to those reported in the literature in some cases they are higher. The mass of sprout increased by 8.9-13.8%, the mass of root – by 6.1–11.3%, the total mass of sprout and root – by 7.8–12.7%, compared to the untreated control. Treating options 1 [U = (8… 5) kV and τ = (15… 35) s] and 4 [U = (6… 3) kV and τ = (5… 25) s] had the highest effect.

Compared to the corresponding untreated control for each storage period, the electromagnetic impact has a stimulating effect in the two storage periods: the mass of sprout – by 11.4–16.8% and 5.3–10.4%, respectively in one- and two-year storage of seeds; mass of root – by 5.1–16.1% and 2.7–8.1%; total mass of sprout and root – by 10.8–16.5% and 4.5–9.1%. Variants with very high values were reported in some cases during the one-year storage of seeds. The variety Helius was the most responsive to electromagnetic impact, the total mass of sprout and root in one-year storage of seeds increased by 48.5%, in option 1.

Conclusion

Pre-sowing electromagnetic treatments, with the selected values of controllable factors, had a stimulating effect on the mass of sprout and root of cotton seeds stored for one and two years before treatment. The mass of sprout increased by 8.9–13.8%, the mass of root – by 6.1–11.3%, the total mass of sprout and root – by 7.8–12.7%. Options 1 [U = (8…5) kV and τ = (15…35) s] and 4 [U = (6…3) kV and τ = (5…25) s] had the highest stimulating effects.

The varieties responded specifically to the two storage periods, in most cases by lowering of the parameters studied during the two-year storage of seeds, most pronounced for the Nelina variety.

Seeds stored for one year, after pre-sowing electromagnetic treatment had higher mass of sprout and higher mass of root than seeds stored for two years. The sprout mass of seeds stored for one year was higher by 11.4–16.8%, the root mass – by 11.6–16.1% (in options 1, 2 and 4), the total mass of sprout and root – by 10.8–16.9%, compared to the control variant – Chirpan-539, one year of seed storage, without treatment.

Compared to the corresponding untreated control for each storage period, the electromagnetic impact had a stimulating effect in both storage periods: for the mass of sprout – by 11.4–16.8% in option 1 and 5.3–10.4% in options 1 and 4, respectively one- and two-year storage; for the mass of root – by 5.1–16.1% in options 1 and 4 and 2.7–8.1% in option 4; for the total mass of sprout and root – by 10.8–16.5% in option 1 and 4.5–9.1% in option 4.

Variants with significant higher values than the control variant – Chirpan-539 variety, one-year storage, untreated seeds, were reported only in the one-year storage of seeds.

Compared to the corresponding untreated control of each variety and storage period, stimulating effect of the pre-sowing electromagnetic treatment was observed for all varieties, in both storage periods, except for Nelina variety, only in the one-year storage.

Helius variety was the most responsive to the electromagnetic impact, the total mass of sprout and root of seeds stored for one year increased by 28.7% to 48.5% in option 1. The mass of root increased most for Nelina variety, in the one-year storage of seeds, in options 1, 2 [U = (6…3) kV, τ = (15…35) s] and 3 [U = (8…5) kV, τ = (5…25) s].

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