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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. I. Length of sprout and root

Minka Koleva[1*] and Kiril Sirakov[2]

[1] *Agricultural Academy, Field Crops Institute, 6200 Chirpan, Bulgaria*
[2] *Ruse University "Angel Kanchev", 7017 Ruse, Bulgaria*
[*]*Corresponding autor:* m_koleva2006@abv.bg

Abstract

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Seeds of five cotton varieties – Chirpan-539, Helius, Trakia, Natalia and IPK Nelina, stored for one and two years, were subjected to pre-sowing electromagnetic treatments. Stimulating effect of treatments on the length of sprout and root has been established. Sprout length increased by 10.1-15.3% compared to the untreated control. Options 1 [U = (8…5)kV and τ = (15…35)s] and 4 [U = (6…3)kV and τ = (5…25)s] were the best ones. The length of root increased by 5.3-17.5% and the total length of sprout and root, as a generalized index, increased by 7.5-16.4%. Option 4 was the best one. Electromagnetic treatments had different impact on seeds under different storage durations due to their different physiological state. All options of electromagnetic treatment had a positive effect on the length of sprout and root, respectively on the total length of sprout and root, for the seeds stored for one year. During the two-year storage of seeds, all treatments showed significant and insignificant lower values than the control variant. Greater length of root and sprout than the control variant (Chirpan-539, one-year storage, untreated seeds) was found only in the one-year storage of seeds, for individual varieties. The total length of sprout and root during the one-year storage of seeds was greater for the varieties: Natalia – by 22.9-24.1% in options 1 and 4; Nelina – by 17.8-23.0% in options 2 [U = (6…3)kV and τ = (15…35)s], 4 and 5 [U = (4…2)kV and τ = (5…25)s]); Helius – by 16.5-19.5% in options 2 and 4; Chirpan-539 – 15.3% in option 4. Compared to the untreated controls corresponding to each variety and period of storage, a positive effect on the length of sprout and root was observed for all varieties in both storage periods. The strongest stimulating effect of pre-sowing electromagnetic treatments was found for the variety Helius, in the one-year storage of seeds, the total length of sprout and root increased by 36.5-43.9% in options 1, 2 and 4, compared to the respective control.

Keywords: pre-sowing electromagnetic treatment; cotton seeds; duration of storage; sprout; root; length

Introduction

Modern agriculture is based on enhanced intensification, with a high degree of chemicalization (Pavlova & Dochev, 2010) and significant investment costs to increase crop yields. The growing need for environmentally friendly agricultural products necessitates the search for new, more harmless technologies to increase production. Along with the application of traditional methods (Kirchev et al., 2012; Delibaltova & Kirchev, 2010) using fertilizers and agrochemicals (Atanasov & Dochev, 2008), it is necessary to develop and implement environmentally friendly techniques.

In the last decade, more and more attention has been paid to organic products that are the result of organic farming. A number of developed countries are developing special programs and subsidizing organic farming.

Many scientists are looking for other, non-traditional ways to stimulate genetic potential of plants, which will lead to increased yields and production of environmentally friendly agricultural products, with lower capital investment.

Main unit in the technology for cotton growing is the preparation of seeds for sowing. Seeds are the main reproductive structure of plant and realization of variety potential for yield and quality largely depends on their physiological state. Properly stored, seeds can remain viable for long enough. But even for seeds stored under optimal conditions, their viability decreases as a result of aging, which is a physiological and genetically determined process, and is individual for each plant species and variety (Sastry et al., 2008). Using of seeds with impaired sowing qualities has a negative effect on the germination and viability, which lead to crops with uneven density and development, and low productivity. Simultaneous and rapid germination of seeds is a prerequisite for the development of well-garnished crops with optimal density, which creates conditions for the realization of genetic potential for yield and high quality of production.

A number of authors reported a stimulating effect on the sowing qualities of seeds and a subsequent increase in yield after pre-sowing electromagnetic impact in some crops. Positive results have been obtained after electromagnetic field treatment of maize seeds (Palov et al., 2000; 2001a; 2001b 2005), wheat (Sirakov et al., 2007), barley (Kasakova et al., 2018; 2019), rapeseed (Palov et al., 2012), vegetable seeds (Kuzmanov et al., 2010, Ganeva et al., 2013; 2014; 2015; Sirakov et al., 2013; 2014; 2015; 2016a; Antonova et al., 2013; 2014; 2018). Pre-sowing treatment of cotton seeds in an electromagnetic field led to almost twice the yields compared to untreated control seeds (Leelapriya et al., 2003). After pre-sowing electromagnetic treatment of cotton seeds, an increase in yields was found for the Bulgarian varieties Beli Izvor and Ogosta (Bozhkova et al., 1993; Palov et al., 1994). An increase in earliness and yield up to 12% was achieved for the variety Chirpan-539 after pre-sowing electromagnetic treatment of seeds at initial values of controllable factors: voltage U_1=8kV and duration of treatment=15s (Palov et al., 2008; Radevska et al., 2008). Similar results, increased yields and earlier maturation of cotton have been obtained by other authors (Stoilova et al., 2011).

The parameters of effective electromagnetic treatments of seeds of three Bulgarian triticale varieties have been established (Muhova et al., 2016; Sirakov et al., 2016a, b; 2018; 2019). Of these, the Boomerang variety reacted most positively to the electromagnetic impact.

From the production experiments conducted in different regions of the country, increased yields were realized, expressed as a percentage compared to the control: for corn (4.2...22.5)%/control; for wheat (2.5...9.1)%/control (Zahariev, 2015; Palov et al., 2016; Zahariev et al., 2013).

Obtained positive results showed high efficiency of electromagnetic fields for stimulating the sowing qualities of seeds and are a prerequisite for the research in this direction to continue.

Until now there is no data in the specialized literature on the effect of electromagnetic fields on stored seeds set aside for reserve.

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

Material and Methods

Seeds of five cotton varieties Chirpan-539, Helius, Trakia, Natalia and IPK Nelina were the object of 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 different duration of exposure. For the purposes of pre-sowing electromagnetic treatments, a method with periodic decrease of values of voltage U between electrodes of the working camera and increase the duration of impact was used (Palov et al., 1995).

Based on previous research (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 changes should occur in the seeds, which will subsequently favor the development of plants.

Some of 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. 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 25°C and humidity 95%. Length of root and sprout of germinated seeds was measured on the seventh day of their setting into the thermostat. Results of each sample were averaged.

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)					

The results were processed by three-factor 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.

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 Discusion

Analysis of variance of studied parameters showed that the periods of storage as an individual factor had the strongest influence on the root length (35.95%) and total length of sprout and root (35.5%) (Table 2), which means that these characteristics differed significantly for the two storage periods (one and two years). The varieties × storage periods interaction had the strongest influence on the length of sprout (26.03%), i.e. the varieties reacted differently to the two storage periods regarding this characteristic. Varieties and treatments, as separate factors, had a weak but significant influence. All interactions had a significant effect on the root length. The interactions varieties × treatments (A × B) and varieties × treatments × storage periods (A × B × C) were insignificant for the length of sprout, varieties × treatments (A × B) – for the total length of sprout and root.

Of the varieties, as an independent factor, Chirpan-539 variety had the longest sprout length (Table 3). The varieties Natalia and Helius had an insignificant shorter sprout length, while the other two varieties – Trakia and Nelina had a significant shorter length. Natalia variety had significant maximum root length and insignificant maximum total sprout and root length. Trakia variety had an insignificant shorter root length and significant shorter total length of sprout and root, Nelina variety had insignificant shorter total length of sprout and root. The shorter length of sprout negatively affected the total length of sprout and root of seeds of these two varieties.

Of the electromagnetic treatments, all options had a positive effect, the length of sprout increased by 10.1-15.3%, the length of root by 5.3 – 17.5%, and the total length of sprout and root by 7.5% to 16.4%, compared to the untreated control. Options 1 and 4 appeared to be the best for the length of sprout, option 4 – for the length of root and total length of sprout and root.

Table 2. Results of three-way ANOVA for length of sprout, length of root and total length of sprout and root after electromagnetic treatment of seeds of 5 cotton varieties after 1 and 2 years storage

Factors	Degree of freedom	Length of sprout, mm			Length of root, mm			Total length of sprout and root, mm		
		Sum of squares	Sum of squares, (%)	Dispersion	Sum of squares	Sum of squares, (%)	Dispersion	Sum of squares	Sum of squares, (%)	Dispersion
A	4	24.467	6.90	6.1***	25.695	2.87	6.423*	76.08	3.80	19.0**
B	5	10.751	3.03	2.150*	20.187	2.254	4.037	48.19	2.40	9.64*
C	1	77.261	21.79	77.3***	321.99	35.95	322***	711.4	35.50	711***
A×B	20	20.793	5.86	1.040	89.611	10.00	4.48**	131.6	6.57	6.582
A×C	4	92.301	26.03	23.1***	62.955	7.03	15.8***	289.7	14.46	72.4***
B×C	5	15.215	4.29	3.043**	42.539	4.75	8.507**	99.02	4.94	19.8***
A×B×C	20	23.643	6.67	1.18	93.132	10.40	4.657**	158.9	7.93	7.95*
Errors	118	89.563	25.26	0.759	238.55	26.64	2.022	488.1	24.36	4.137

Table 3. Independent action of factors

Factors	Length of sprout, mm	In % to control	Length of root, mm	In % to control	Total length of sprout and root, mm	In % to the control
Varieties						
Chirpan-539	9.280	100.0	12.275	100.0	21.544	100.0
Trakia	8.272	89.1^{000}	12.098	98.6	20.365	94.5^{0}
Helius	9.037	97.4	12.553	102.3	21.584	100.2
Natalia	9.225	99.4	12.913	105.2^{*}	22.138	102.7
Nelina	8.560	92.2^{000}	12.412	101.1	20.959	97.3
GD 5.0%	0.406	4.4	0.647	5.3	0.949	4.4
GD 1.0%	0.537	5.8	0.854	6.9	1.255	5.8
GD 0.1%	0.693	7.5	1.100	9.0	1.618	7.5
Treatments						
1	9.301	115.3^{***}	12.419	106.8^{*}	21.721	110.5^{***}
2	8.877	110.1^{***}	12.366	106.4^{*}	21.234	108.0^{**}
3	8.883	110.2^{***}	12.240	105.3^{*}	21.130	107.5^{**}
4	9.227	114.4^{***}	13.655	117.5^{***}	22.882	116.4^{***}
5	8.896	110.3^{***}	12.397	106.0^{*}	21.282	108.3^{**}
6	8.063	100.0	11.625	100.0	19.659	100.0
GD 5.0%	0.445	5.5	0.647	5.6	1.039	5.3
GD 1.0%	0.589	7.3	0.855	7.3	1.375	7.0
GD 0.1%	0.759	9.4	1.100	9.5	1.722	8.8
Storage terms						
1 year	9.601	100.0	13.740	100.0	23.341	100.0
2 years	8.148	84.9^{000}	11.160	81.2^{000}	19.295	82.7^{000}
GD 5.0%	0.257	2.7	0.373	2.7	0.600	2.6
GD 1.0%	0.340	3.5	0.493	3.6	0.793	3.4
GD 0.1%	0.438	4.6	0.635	4.6	1.023	4.4

Seeds stored for two years had significant lower values for the studied parameters than seeds stored for one year.

As a result of the cultivars × treatments interaction, the maximum sprout length was observed for the varieties Helius, in options 1 and 4, Chirpan-539 and Natalia, in option 1 (Table 4). The length of sprout was higher by 11.7-17.1% compared to the control variant (variant 6 of Chirpan-539 variety, untreated seeds). Helius variety, in options 1, 2 and 4, and Trakia variety, in options 3, 4 and 5, showed the strongest increase in the length of sprout, respectively by 21.1-36.4% and 17.7-20.7%, compared to untreated control corresponding of each variety.

Significant higher root length was observed for the varieties Chirpan-539, in options 4 and 5, Helius and Natalia, in options 1 and 4, and Nelina, in options 4. The root length was longer by 16.4-23.6% compared to the control variant.

Compared to the untreated control corresponding to each variety, Chirpan-539 and Helius varieties reacted most strongly, the length of root was higher by 21.2% and 23.1%, respectively, in options 4. Natalia and Nelina varieties showed higher root length by 11.6% and 17.2%, also in option 4, for Trakia variety by 16.2%, in option 3, compared to the respective controls (Figure 1).

The total length of sprout and root was significantly higher by 15.4% and 12.8%, in options 3 and 4, for Chirpan-539 variety, by 16.8-20.8% and 14.9-17.8%, in options 1 and 4, for Helius and Natalia varieties, than the control variant Chirpan-539, untreated seeds.

Helius variety reacted positively to the electromagnetic impact with the highest values for the studied characteristics. The root grew faster than the sprout and was more important for the formation of total length of sprout and root.

As a result of the varieties × storage periods interaction, in the one-year storage of seeds, Nelina variety had the highest indexes for the length of sprout and root and total length of sprout and root, respectively 11.1%, 9.6% and 10.2% over the control variant (Chirpan-539, one year of storage) (Table 5). Natalia variety showed significant longer sprout length by 7.7% and total length sprout and root by 6.5%. Trakia variety had significant shorter length of sprout and respectively shorter total length of sprout and root.

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

Varietis	Treat-ments	Length of sprouts, mm	In % to control	Length of root, mm	In % to control	Total length of sprout and root, mm	In % to the control
Chirpan-539	1	9.740	111.7^{*}	10.940	95.3	20.680	102.4
	2	8.917	102.3	11.333	98.8	20.233	100.2
	3	9.427	108.1	12.637	110.1	22.063	109.3
	4	9.392	107.7	13.912	121.2^{**}	23.307	115.4^{**}
	5	9.485	108.8	13.352	116.4^{*}	22.787	112.8^{*}
	6	8.719	100.0	11.474	100.0	20.193	100.0
Trakia	1	8.237	94.5	11.935	104.0	20.177	99.9
	2	8.318	95.4	12.577	109.6	20.895	103.5
	3	8.705	99.8	12.727	110.9	21.432	106.1
	4	8.487	97.3	12.542	109.3	21.028	104.1
	5	8.672	99.5	11.855	103.3	20.493	101.5
	6	7.213	82.7^{000}	10.952	95.5	18.165	89.9
Helius	1	9.922	113.8^{*}	13.670	119.1^{**}	23.592	116.8^{**}
	2	9.067	101.8	12.835	111.9	21.868	108.3
	3	8.775	104.0	11.277	98.3	20.052	99.3
	4	10.213	117.1^{**}	14.180	123.6^{**}	24.393	120.8^{***}
	5	8.755	100.4	11.837	103.2	20.592	102.0
	6	7.487	85.9^{0}	11.519	100.4	19.005	94.1
Natalia	1	9.785	112.2^{*}	13.408	116.9^{*}	23.193	114.9^{*}
	2	9.155	105.0	12.502	108.9	21.657	107.3
	3	9.173	105.2	12.305	107.2	21.478	106.4
	4	9.610	110.2	14.182	123.6^{***}	23.792	117.8^{**}
	5	8.898	102.1	12.380	107.9	21.278	105.4
	6	8.727	100.1	12.703	110.7	21.429	106.1
Nelina	1	8.823	101.2	12.140	105.8	20.963	103.8
	2	8.930	102.4	12.583	109.7	21.515	106.5
	3	8.337	95.6	12.253	106.8	20.623	102.1
	4	8.433	96.7	13.457	117.3^{*}	21.890	108.4
	5	8.668	99.4	12.560	109.5	21.260	105.3
	6	8.168	93.7	11.479	100.0	19.505	96.6
GD 5.0%		0.996	11.1	1.585	13.8	2.325	11.5
GD 1.0%		1.317	15.1	2.093	18.2	3.074	15.2
GD 0.1%		1.697	19.5	2.695	23.5	3.963	19.6

All varieties had a significant shorter length of sprout and root, and respectively a shorter total length of sprout and root, in the two-year storage, compared to the control variant and the one-year storage. Chirpan-539 variety was an exception, for it the length of sprout during the two-year storage was insignificant smaller. The length of sprout for Trakia variety was the same in the two storage periods.

Electromagnetic treatments had different impact on seeds with different duration of storage. As a result of the treatments × storage periods interaction (B × C), a significant higher effect of treatments compared to the control (option 6, one-year storage) was observed only in the one-year storage of seeds (Table 6). The length of sprout, in all options, was higher by 11.3-18.6%, of root – by 8.3-22.8%, the total length of sprout and root – by 7.6-21.1%. The length of root was insignificant higher only in option 3. Option 4 was best for the three parameters, options 1 and 2 showed good results. In the two-year storage of seeds, the length of sprout was significant less than the control only in one of cases (option 2). The length of root in all treatment options was significant shorter, except for option 4. The total length of sprout and root was respectively with significant and insignificant lower values than the control. The weaker effect of electromagnetic impact during this storage period could be

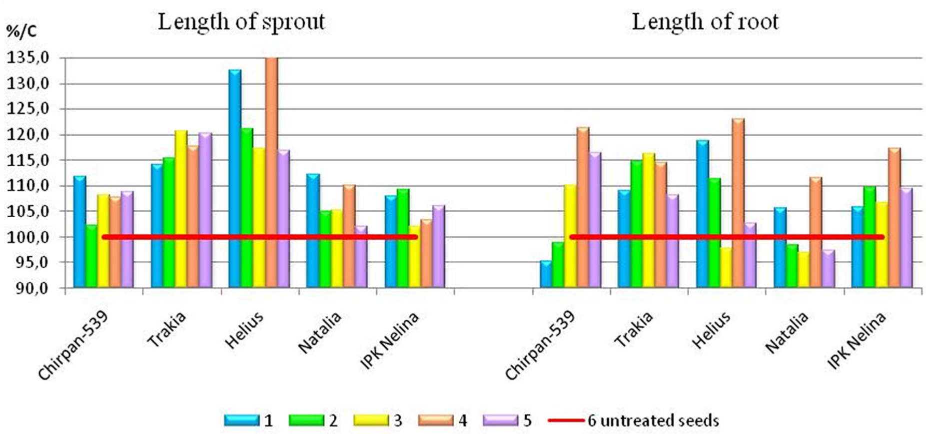

Fig. 1. Effect of pre-sowing electromagnetic treatments on length of sprout (mm) and length of root (mm) of seeds of five cotton varieties, in % to the corresponding of each variety untreated control (%/C)

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

Varietis	Length of sprouts, mm	In % to control	Length of root, mm	In % to control	Total length of sprout and root, mm	In % to the control
Chirpan-539						
1 year	9.491	100.0	13.497	100.0	22.966	100.0
2 years	9.068	95.5	11.052	81.88^{000}	20.122	87.6^{000}
Trakia						
1 year	8.256	87.0^{000}	13.094	97.0	21.349	92.9^{0}
2 years	8.288	87.3^{000}	11.102	82.3^{000}	19.381	84.4^{000}
Helius						
1 year	9.531	100.4	13.097	97.0	22.628	98.5
2 years	8.542	90.0^{00}	12.001	88.9^{00}	20.654	89.9^{000}
Natalia						
1 year	10.226	107.7^{*}	14.223	105.4	24.449	106.5^{*}
2 years	8.224	86.7^{000}	11.603	86.0^{000}	19.827	86.3^{000}
Nelina						
1 year	10.504	111.1^{***}	14.789	109.6^{**}	25.315	110.2^{***}
2 years	6.616	69.7^{000}	10.035	74.3^{000}	16.604	72.3^{000}
GD 5.0%	0.575	6.1	0.915	6.8	1.342	5.8
GD 1.0%	0.760	8.0	1.208	8.9	1.775	7.7
GD 0.1%	0.980	10.3	1.556	11.5	2.288	10.0

explained by the different physiological state of seeds, stored for one and two years. Untreated controls of seeds stored for two years had much lower rates than untreated controls of seeds stored for one year.

In the case of two years of storage, all options had a positive effect on the corresponding untreated control (option 6, two years of storage, untreated seeds). The length of sprout for treated options was higher by 5.2-12.4% in option 1, the length root – by 4.5-11.3% in option 4, the total length of sprout and root – by 2.3-11.0% in option 4 (Figure 2).

As a result of the three main factors interaction (A × B × C) greater length of sprout and root over the control variant (variant 6 – variety Chirpan-539, one-year storage, untreated seeds) was observed only for seeds stored for one year. Significant longer sprout length was found for the varieties: Helius – by 15.7-17.9%, in options 4 and 1; Natalia – by 19.1-21.5%, in options 4 and 1; Nelina – by 15.9%, 18.4% and 21.5%, in options 1, 5 and 2 (Table 7). Significant higher root length was found for the varieties: Chirpan-539 – by 17.6%, in option 4; Helius – by 23.1%, in option 2, Natalia – by 23.8-27.7%, in options 1 and 4 and Nelina – by 18.7-30.5%, in options 5 and 4. The total length of sprout and root

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

Term of storage	Treat-ments	Length of sprout, mm	In % to control	Length of root, mm	In % to control	Total length of sprout and root, mm	In % to the control
1 year	1	10.085	118.0^{***}	13.998	112.1^{**}	24.083	114.5^{***}
	2	9.782	114.4^{***}	13.995	112.1^{**}	23.771	113.0^{***}
	3	9.515	111.3^{**}	13.099	104.9	22.627	107.6^{**}
	4	10.139	118.6^{***}	15.332	122.8^{***}	25.471	121.1^{***}
	5	9.541	111.6^{**}	13.527	108.3^{*}	23.061	109.6^{**}
	6	8.547	100.0	12.488	100.0	21.035	100.0
2 years	1	8.517	99.6	10.839	86.8^{000}	19.359	92.0
	2	7.973	93.3^{0}	10.737	86.0^{000}	18.697	88.9^{00}
	3	8.252	96.5	11.380	91.1^{0}	19.632	93.3^{0}
	4	8.315	97.3	11.977	95.9	20.293	96.5
	5	8.250	96.5	11.266	90.2^{00}	19.503	92.7^{0}
	6	7.579	88.7^{00}	10.762	86.2^{000}	18.284	86.9^{00}
GD 5.0%		0.630	7.4	0.915	7.3	1.471	7.0
GD 1.0%		0.832	9.7	1.208	9.7	1.944	9.2
GD 0.1%		1.074	12.6	1.555	12.5	2.506	11.9

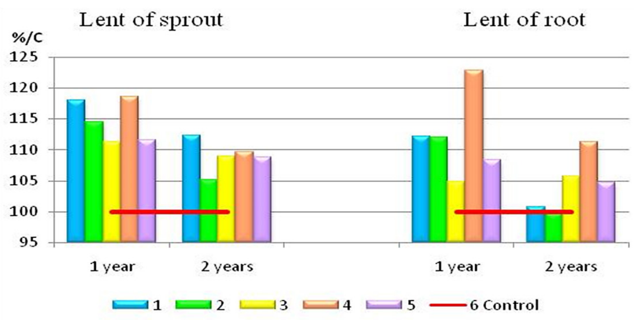

Fig. 2. Effect of pre-sowing electromagnetic treatments on length of sprout (mm) and length of root (mm) of seeds stored for one and two years, in % to the corresponding untreated control of each storage period (%/C)

as an generalized indicator showed significant higher values from that of the control variant for the same varieties and options: Chirpan-539 – by 15.3%, in option 4; Helius – by 16.5-19.5%, in options 4 and 2; Natalia – by 22.9-24.1%, in options 1 and 4, and Nelina – by 17.8%, 18.8% and 23.0%, in options 2, 5 and 4. In the two-year storage of seeds, the total length of sprout and root was significant and insignificant less than the control variant. An exception was Helius variety, showed insignificant higher values in options 1 and 4.

In comparison with the untreated controls, corresponding to each variety and period of storage, a positive effect of the electromagnetic impact was observed for all studied parameters, for all varieties and for some of them in both storage periods. From Figure 3a, it can be seen, that the Helius variety reacted most strongly to the pre-sowing electromagnetic treatment for the length of sprout during the one-year storage of seeds. All options had a positive effect during the two storage periods, compared to the corresponding controls. The length of sprout increased by 44.5–48.8% in options 1, 2 and 4, for the seeds stored for one year and by 27.4%, in option 4, fot the seeds stored for two years.

For Trakia variety, in the one-year storage of seeds, options 3 and 4 were the best, in the two-year storage – 3 and 5, and the increase in sprout length was 22.4-23.0% and 19.0-21.3%, respectively.

For Natalia variety, a positive effect of electromagnetic treatments was observed only during the one-year storage of seeds.

Regarding the length of root, for Helius and Trakia varieties, and for seeds stored for one year, all variants of treatments also had a positive effect compared to the respective controls (Figure 3b). Stimulating effect of electromagnetic impact was also most pronounced for the Helius variety – 36.5-43.5% over the respective control, in options 4 and 2. Relatively high stimulating effect – 21.5% and 23.2%, for the seeds stored for one year, was observed for the varieties Nelina and Trakia, in option 4. Treatment option 4 appears to be the best for all varieties. During the two-year storage of seeds, the stimulating effect was most pronounced for the Chirpan-539 variety – 25.8%, in option 4.

Trakia and Nelina varieties reacted positively to all electromagnetic treatments during the two storage periods, compared to the respective controls, for the total length of sprout and root (Table 7). The effect of treatments was greater for the Trakia variety. Nelina and Chirpan 539 varieties also re-

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

Varietis	Years	Treat-ments	Lenth of sprout, mm	In % to control	Length of root, mm	In % to the control	Total length of sprout and root, mm	In% to the corresponding control
Chirpan-539	1 year	1	9.710	106.3	13.053	102.7	22.763	104.2
		2	8.720	95.5	12.023	94.5	20.710	94.8
		3	9.287	101.7	13.337	104.9	22.623	103.5
		4	10.243	112.1	14.950	117.6*	25.193	115.3*
		5	9.853	107.9	14.903	117.2	24.657	112.8
		6	9.135	100.0	12.715	100.0	21.850	100.0
	2 years	1	9.770	106.9	8.827	69.4^{000}	18.597	85.1
		2	9.113	90.9	10.643	83.7	19.757	90.4
		3	9.567	104.7	11.937	93.9	21.503	98.4
		4	8.540	93.5	12.873	101.2	21.420	98.0
		5	9.117	99.8	11.800	92.8	20.917	95.7
		6	8.303	90.9	10.233	80.5^{0}	18.537	84.8^{0}
Trakia	1 year	1	8.267	90.5	13.147	103.4	21.413	98.0
		2	8.300	90.9	13.693	107.7	21.993	100.7
		3	8.687	95.1	13.010	102.3	21.697	99.3
		4	8.730	95.6	13.983	110.0	22.713	103.9
		5	8.453	92.5	13.377	105.2	21.830	99.9
		6	7.097	77.7^{00}	11.353	89.3	18.450	84.4^{0}
	2 years	1	8.207	89.8	10.723	84.3	18.940	86.7
		2	8.337	91.3	11.460	90.1	19.797	90.6
		3	8.723	95.5	12.443	97.9	21.167	96.9
		4	8.243	90.2	11.100	87.3	19.343	88.5
		5	8.890	97.3	10.333	81.3^{0}	19.157	87.7
		6	7.330	80.2^{0}	10.550	83.0	17.880	81.8^{0}
Helius	1 year	1	10.770	117.9*	13.683	107.6	24.453	111.9
		2	10.457	114.5	15.647	123.1**	26.103	119.5*
		3	9.310	101.9	11.710	92.1	21.020	96.20
		4	10.567	115.7*	14.890	117.1	25.457	116.5*
		5	8.847	96.8	11.743	92.3	20.590	94.2
		6	7.237	79.2^{00}	10.907	85.8	18.143	83.0^{0}
	2 years	1	9.073	99.3	13.657	107.4	22.730	104.0
		2	7.677	84.0^{0}	10.023	78.8^{0}	17.633	80.7^{0}
		3	8.240	90.2	10.843	85.3	19.083	87.3
		4	9.860	107.9	13.470	105.9	23.330	106.8
		5	8.663	94.8	11.930	93.8	20.593	94.2
		6	7.737	84.7^{0}	12.130	95.4	19.867	90.9

Table 7. Continued

Natalia	1 year	1	11.103	121.5**	15.743	123.8***	26.847	122.9**
		2	10.360	113.4	13.940	109.6	24.300	111.2
		3	10.120	110.8	13.087	102.9	23.207	106.2
		4	10.880	119.1*	16.237	127.7***	27.117	124.1**
		5	9.737	106.6	12.527	98.5	22.263	101.9
		6	9.153	100.2	13.805	108.6	22.958	105.1
	2 years	1	8.467	92.7	11.073	87.1	19.540	89.4
		2	7.950	87.0	11.063	87.0	19.013	87.0
		3	8.227	90.1	11.523	90.6	19.750	90.4
		4	8.340	91.3	12.127	95.4	20.467	93.7
		5	8.060	88.2	12.233	96.2	20.293	92.9
		6	8.330	91.2	11.600	91.2	19.900	91.1
Nelina	1 year	1	10.577	115.9*	14.363	113.0	24.940	114.1
		2	11.073	121.2**	14.670	115.4	25.747	117.8*
		3	10.170	113.3	14.353	112.9	24.590	112.5
		4	10.273	112.5	16.600	130.5***	26.873	123.0**
		5	10.817	118.4*	15.087	118.7*	25.967	118.8*
		6	10.113	110.7	13.660	107.4	23.773	108.8
	2 years	1	7.070	77.4^{00}	9.917	78.0	16.987	77.7^{00}
		2	6.787	74.3^{00}	10.497	82.5^{0}	17.283	79.1^{00}
		3	6.503	71.2^{000}	10.153	79.9^{0}	16.657	76.2^{00}
		4	6.593	72.3^{000}	10.313	81.1^{0}	16.907	77.4^{00}
		5	6.520	71.4^{000}	10.033	78.9^{0}	16.553	75.7^{00}
		6	6.223	68.1^{000}	9.297	73.1^{00}	15.520	71.0^{000}
GD 5.0%			1.409	15.4	2.241	17.6	3.289	15.1
GD 1.0%			1.863	20.4	2.961	23.3	4.348	19.9
GD 0.1%			2.401	26.3	3.810	30.0	5.604	25.6

acted positively to some treatments during the two storage periods. The strongest stimulating effect of treatments was found for Helius variety, in the one-year storage of seeds, in options 1, 2 and 4, the total length of sprout and root increased by 34.8-43.9% over the respective control. Natalia variety showed a positive effect of electromagnetic treatments only during one-year storage, in options 1 and 4. The best treatment option was 4, which could be applied to all varieties during both storage periods. In previous studies (Bozhkova et al., 1993) option 4 gave the best results regarding the electromagnetic impact on the seeds of cotton variety "Beli Izvor".

Option 3 could be used in two-year storage of seeds of Chirpan-539 and Trakia varieties.

The results obtained are in accordance with those reported by other authors in cotton and other crops, which also found a stimulating effect of electromagnetic fields on the initial development of seeds, plants and subsequent increase in yield. Electromagnetic fields improved the oregano rooting and vegetative propagation, plant growth and yield in two corn types, germination and initial growth stages of cotton (Bilalis et al., 2012a; 2012b; 2012c) and also increased the accumulation of chemical elements in plants (Bilalis et al., 2013). A number of authors reported an increase in length of sprout and root of onion (Alexander & Doijode, 1995), corn (Aladjadjiyan, 2002), rice (Florez et al., 2004; Alvarez et al., 2019; 2021), chickpeas (Vashisth & Nagarajan, 2008).

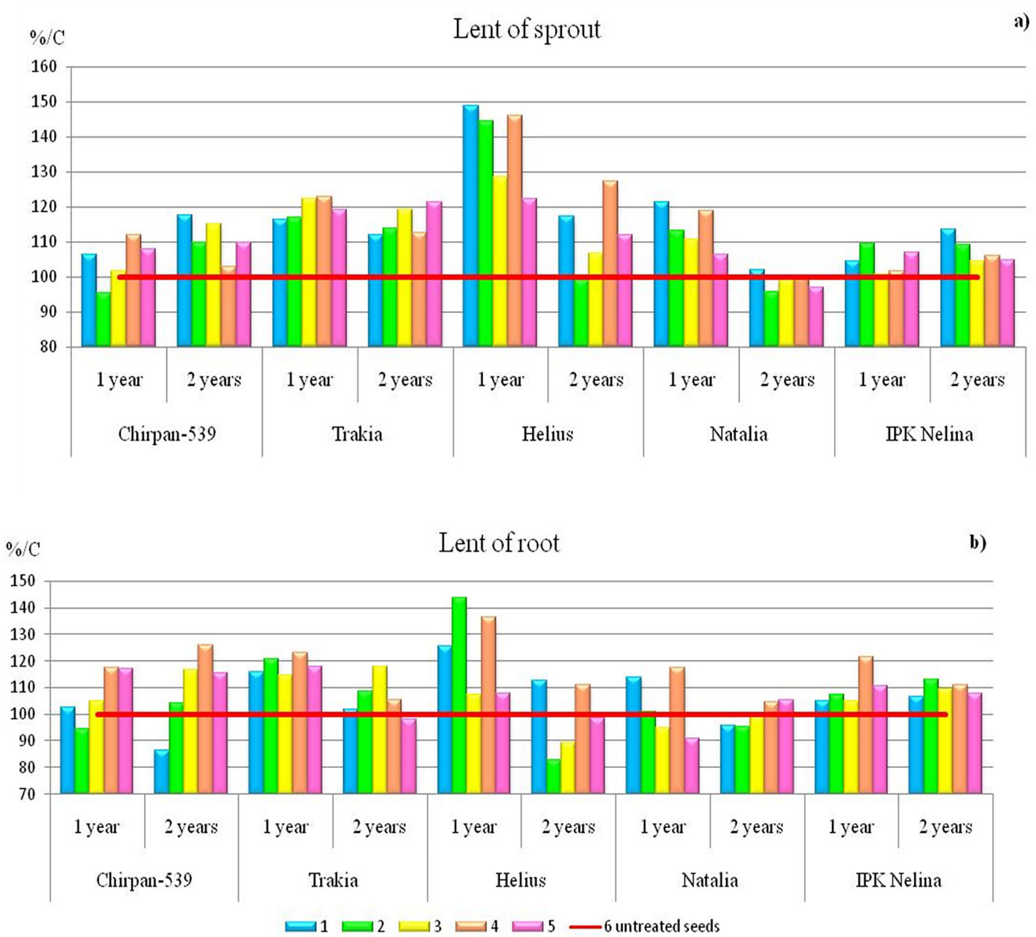

Fig. 3. Effect of pre-sowing electromagnetic treatments on length of sprout (mm) (*a*) and length of root (mm) (*b*) of seeds stored for one and two years, in % to the corresponding untreated control of each variety and storage period (%/C)

Studies conducted in our country showed that after pre-sowing electromagnetic treatment (with a voltage frequency of 50 Hz) of pea seeds, length of sprout increased by 5.5%, length of root – by 18.6% (Palov et al., 2013a). The parameters of efficient electrical treatments of seeds from: maize hybrids (U = 1.65kV and τ = 10s) (Palov et al., 2013b) and wheat seeds (U = 3kV and τ = 35s) (Kostov, et al., 2014) have been established. Stimulation of the observed laboratory parameters of root length (l root) and sprout (l sprout) was achieved – for seeds of maize hybrids: l root=120.6%/control, l sprout = 113.9%/ control; for wheat seeds: l root = 102.2%/control, l sprout = 110%/control (Zahariev et al., 2013; Zahariev, 2015).

As a result of studies performed with an appropriate combination of controllable factors, it was found possibility of stimulating length of roots up to 33.0%, length of sprouts up to 7.6%, compared to the untreated control (Sirakov et al., 2018; 2019).

The results obtained for the length of sprout and root of seeds of studied five cotton varieties were comparable to those reported by other authors and even much higher, depending on treatment option, variety and duration of seed storage.

For the Helius variety, during the one-year storage of seeds, a high stimulating effect up to 44.5-48.8%, in options 1, 2 and 4, was found for the length of sprout and up to 36.5-43.5%, in option 4 and 2, for the length of root.

Results of study also show that electromagnetic treatments stimulate the growth and development of sprout and root and give a better start to the initial development of root system of seeds. Length of sprout and root of treated seeds, stored for one and two years, for most of applied treatment options were better than the control values.

Conclusion

All pre-sowing electromagnetic treatments, as an independent factor, had a stimulating effect on the length of sprout and root. Sprout length increased by 10.1-15.3% compared to the untreated control, options 1 [U = (8…5) kV and τ = (15…35) s] and 4 [U = (6…3) kV and τ = (5…25) s] were the best. Root length increased by 5.3-17.5% and the sprout and root total length – by 7.5-16.4%, option 4 was the best for both parameters.

All options had a positive effect on the length of sprout and root, and respectively on the total length of sprout and the root, in seeds stored for one year. For the length of sprout, the best options were 1 and 4, in which the stimulating effect was 18.0-18.6% over untreated control. For the length of root and total length of sprout and root, the best option was 4, with the highest stimulating effect by 22.8% and 21.4%, respectively.

Seeds stored for two years had shorter sprout and root lengths than the control variant and seeds stored for one year.

Variants of electromagnetic treatment with longer length of sprout and root, compared to the control variant (Chirpan-539 variety, one-year storage, untreated seeds) were found only in seeds stored for one year. The length of sprout was the highest for the varieties Natalia – 21.5%, in option 1 and Nelina – 21.2%, in option 2; the length of root – for Nelina variety, option 4 – 30.5%; the total length of sprout and root – for the varieties Natalia – 22.9-24.1%, in options 1 and 4 and Nelina – 23.0%, in options 4.

Compared to the untreated controls, corresponding to each variety and storage period, a positive effect of pre-sowing electromagnetic treatments for the length of sprout and root was found for all varieties, in both storage periods.

Strongest stimulating effect was found for Helius variety in the one-year storage of seeds. Sprout length increased by 44.5-48.8% in options 1, 2 and 4, root length – by 36.5 – 43.5% in options 2 and 4, total sprout and root length – by 34.8-43.9% in options 1, 2 and 4.

In the two-year storage of seed, the length of sprout and total length of sprout and root most strongly increased for the Helius variety – 27.4% and 17.4%, respectively, in option 4, the length of root – for the Chirpan-539 variety – 25.8% in option 4.

The best electromagnetic treatment was option 4, which could be applied to all varieties in both seed storage periods. Option 2 could be used in one-year storage of seeds of Helius variety, option 3 – in two-year storage of seeds of Chirpan-539 and Trakia varieties.

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