AGRICULTURAL SCIENCE AND TECHNOLOGY, VOL. 13, No 4, pp 395-403, 2021
Published by Faculty of Agriculture, Trakia University, Bulgaria
ISSN 1313-8820 (print)
ISSN 1314-412X (online)
http://www.agriscitech.eu
DOI: 10.15547/ast.2021.04.064

Agriculture and Environment

Influence of duration of storage and pre-sowing electromagnetic treatment on the development of the primary root system of cotton seeds

M. Koleva*, M. Radevska

Field Crops Institute, 6200 Chirpan, Bulgaria

(Manuscript received 14 August 2021; accepted for publication 26 October 2021)

Abstract. *Seeds of five Bulgarian cotton varieties, stored for one and two years, were subjected to five pre-sowing electromagnetic treatments with different intensity and duration of exposure. It was found that the selected values of controllable factors had stimulating effect on the total length and total mass of sprout and root. The total length of sprout and root increased by 7.5-16.4% ($p<0.05$), the total mass of sprout and root increased by 7.8-12.7% ($p<0.05$). The best treatment options were 1[U=(8…5)kV, τ =(15…35)s] and 4[U=(6…3)kV, τ =(5…25)s]. Electromagnetic treatments had stronger positive effect on seeds stored for one year. Compared to the untreated control, corresponding to each storage period, the electromagnetic impact had stimulating effect for both storage periods: for the total length of sprout and root the increase was by 7.6-21.1% and 2.3-11.0% at option 4; for the total mass of sprout and root it was by 10.8-16.5% at option 1 and 4.5-9.1% at option 4, respectively, at one-year and two-year storage of seeds. In comparison with the control Chirpan-539 variety, untreated seeds, one-year storage, higher values for both studied characteristics were found only for seeds stored for one-year: for the total length of root and sprout at the varieties Natalia, treatment options 1 and 4, Nelina and Helius, options 2 and 4 and Chirpan-539, option 1; for the total mass of root and sprout at the varieties Nelina, options 1, 2 and 3 and Chirpan-539, option 5. Compared to the untreated control corresponding to each variety, the stimulating effect of the pre-sowing electromagnetic treatment for the two characteristics was found for all varieties, for both storage periods. The Helius variety was the most responsive to the electromagnetic impact, with the strongest stimulating effect for both characteristics, at the one-year storage of seeds the total length of sprout and root increased most strongly by 34.8-43.9% at options 1, 4 and 2[U=(6…3)kV, τ =(15…35)s], and the total mass of sprout and root increased by 48.5% at options 1.*

Keywords: cotton, electromagnetic stimulation, root, seeds, sprout, storage

Introduction

In the search for alternative methods for ecologically clean agriculture, many authors have used electric, magnetic, electromagnetic and other physical fields to influence the sowing material and to stimulate the initial growth of plants and subsequent increasing of crop yields.

Many results have been reported for magnetic stimulation of the sowing qualities of peas (Iqbal et al., 2012a,b), soybean (Radhakrishnan and Kumari, 2012), triticale (Alvarez et al., 2012; Flórez et al., 2014), crop plants (Pietruszewski and Martínez, 2015), and cereals (Martinez et al., 2017).

Positive results were obtained after treatments in electromagnetic field of corn seeds (Bilalis et al., 2012a, 2013; Aguilar et al., 2015), soybean seeds (Đukić et al., 2017) and vegetable seeds (Bilalis et al., 2013; Ganeva et al., 2013, 2014; Sirakov et al., 2013, 2014, 2015, 2016a; Antonova et al., 2013, 2014, 2018; Antonova-Karacheva and Sirakov, 2020). Electromagnetic field treatments have been shown to increase germination and improve early cotton growth (Bilalis et al., 2012b). Increase in earliness and yield of cotton up to 12% was achieved for the variety Chirpan-539 after pre-sowing electromagnetic treatment of seeds at initial values of controllable factors: voltage U1=8kV and duration of treatment τ=15 s (Stoilova et al., 2011).

Mathematical models have been developed that take into account the influence of many and individual factors on the effect of pre-sowing electrical or electromagnetic treatment (Zahariev, 2014, 2015; Zahariev et al., 2014; Sirakov, 2015a,b).

The parameters of effective electric seed treatments of: maize hybrids (U=1.65kV and τ=10s); wheat (U=3kV and τ=35s) (Palov et al., 2013a, 2016; Zahariev et al., 2013; Zahariev, 2015); three Bulgarian triticale varieties (Muhova et al., 2016; Sirakov et al., 2016b,c, 2018, 2021) have been established.

In our country, more intensive research with cotton has been conducted to study the effect of electromagnetic treatments on the sowing qualities of seeds, with a view to their stimulation and subsequent increase in yield, and the possibilities for enhancing the stimulating effect after different storage periods of treated seeds (after the electromagnetic impact) (Koleva and Radevska, 2020).

The aim of this research was to study the influence of the

*e-mail: m_koleva2006@abv.bg

duration of storage and pre-sowing electromagnetic treatment on the development of the primary root system of cotton seeds stored before treatment.

Material and methods

Seeds of five cotton varieties Chirpan-539, Helius, Trakia, Natalia and 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. A special device developed and patented by a team of scientists at the University of Ruse "Angel Kanchev" was used (Terziev et al., 1995). For the purposes of pre-sowing electromagnetic treatments, a method with periodic decrease of the values of the voltage U between the electrodes of the working camera and increase of 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 In previous studies (Bozhkova et al., 1993) variant of treatment 4 gave the best results regarding the electromagnetic impact on the seeds of cotton variety "Beli izvor". Variant of treatment 5 with the values of the controllable factors indicated in Table 1 was also set. Such pre-sowing electromagnetic treatment was most effective for the seeds of Ogosta cotton variety.

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

Treatment option	Processing steps					
	I		II		III	
	Controllable factors					
	U_1 (κV)	τ_1 (s)	U_1 (κV)	τ_1 (s)	U_1 (κV)	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)					

After electromagnetic treatment, the cotton seeds have stayed for 23 days. According to Palov et al. (1994) this stay, after treatment until sowing, was necessary so that changes could occur in the seeds, which subsequently favor the development of the plants.

Some of the seeds of each variety were not treated and served for control, to compare and report the effect of electromagnetic treatment. After the seed treatment and their stay, laboratory experiments were performed. A total of 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 of the environment - temperature 25ºC and relative humidity 95%. The length and mass of the root and sprout of the germinated seeds were measured on the seventh day of their setting into the thermostat. The data for each sample were averaged and used to calculate the total length and total mass of the sprout and root.

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

Factors	Degree of freedom	Total length of sprout and root			Total mass of sprout and root		
		Sum of squares	Sum of squares, %	Dispersion	Sum of squares	Sum of squares, %	Dispersion
A	4	76.078	3.80	19.019**	0.1289	13.65	0.03***
B	5	48.187	2.40	9.637*	0.0468	4.95	0.009***
C	1	711.437	35.50	711.437***	0.0964	10.21	0.096***
A×B	20	131.648	6.57	6.582	0.0979	10.36	0.0049**
A×C	4	289.703	14.46	72.425***	0.2640	**27.95**	0.065***
B×C	5	99.016	4.94	19.803***	0.0208	2.21	0.0041
A×B×C	20	158.992	7.93	7.950*	0.0605	6.41	0.0030
Errors	118	488.148	24.36	4.137	0.2282	24.16	0.0019

*Factors: A- Varietiy; B- Electromagnetic treatment; C- Duration of storage of seeds before their electromagnetic treatment.

The results for the total length and total mass of the root and sprout were processed by three-way analysis of variance. The ANOVA program was used. The factors of experience were: A - Varieties; B - Electromagnetic treatments; C - Duration of storage of seeds before their electromagnetic treatment.

Variant Chirpan-539 variety (approved for national standard),

untreated seeds, stored for one year, was accepted as a control one for the experiment. In addition, electromagnetic treatments were compared to the controls corresponding to each variety.

Results and discussion

The duration of storage (Factor C) had the strongest influence - 35.50% on the formation of the total length of the root and sprout (Table 2). This means that the seeds stored one year and two years differed significantly in this characteristic. Varieties and treatments, as independent factors, had significant but very weak influence. The influence of the interaction of varieties × treatments has not been significant, which means that the varieties reacted similarly to the treatments. Of the other three interactions that have been significant, the varieties × duration of storage had the greatest weight. This means that the varieties have responded differently to the two storage periods in terms of the total length of the sprout and root.

The analysis of the variance of the total mass of the sprout and root (Table 2) shows that the three main factors and the interactions of varieties × treatments and varieties × duration of storage had significant influence on its formation. The interaction of treatments × duration of storage, as well as the interaction of the three main factors has not been insignificant. The strongest influence - 27.95% was found for the interaction of varieties × duration of storage (Factors A×C). Of the three main factors, the varieties had the strongest influence and the treatments had the weakest.

Total length of sprout and root

Of the varieties, as an independent factor, the largest total length of sprout and root was found for the Natalia variety, which insignificantly exceeded Chirpan-539 variety - control (Table 3). The Helius variety was equal to the control. The Trakia variety had significantly smaller total length of sprout and root, and the Nelina variety had insignificantly smaller length. All variants of electromagnetic treatment, regardless of the variety and storage period, had significant positive effect, the total length of sprout and root was increased by 7.5% to 16.4% at variant 4, compared to the control untreated seeds (Figure 1). Seeds stored for two years had shorter total length of the sprout and root than seeds stored for one year.

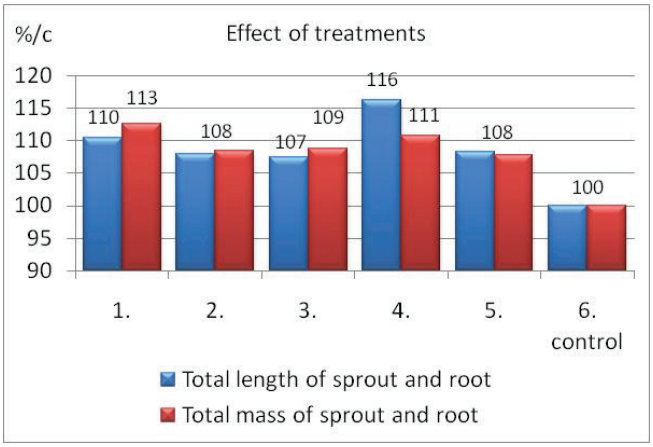

Figure 1. Effect of electromagnetic treatments (Factor B) as an independent factor on the total length and total mass of root and sprout of 5 Bulgarian cotton varieties seeds stored one and two years before treatment

Based on the analysis of variance, the interaction of varieties × treatments was insignificant. However, the calculated smallest significant differences revealed significant values for some varieties, which means, the varieties responded specifically to the electromagnetic impact. For example, for the variety Chirpan-539, treatment variants 4 and 5, the total length of the sprout and root was significantly higher by 15.4% and 12.8% than the control Chirpan-539, untreated seeds.

As for the Helius and Natalia varieties, at treatment variants 1 and 4, the total length of sprout and root was proven to be higher, by 16.8-20.8% and 14.9-17.8%, respectively, and the better variant was 4. Insignificantly higher values were observed for most variants of processing for all varieties: Chirpan-539, option 3-9.3%; Trakia, options 3 and 4 - 6.1% and 4.1%, Helius, option 2 - 8.3%, Natalia, options 2, 3 and 5 - 5.4-7.3%, Nelina, options 2, 4 and 5 - 5.3-8.4%.

The interaction of varieties × storage period determined significantly greater total length of sprout and root for the Nelina and Natalia varieties, when stored one year, by 10.2% and 6.5%, respectively, over the control Chirpan-539 variety, one year of storage. In case of one-year storage of the seeds, the Helius variety had a smaller but insignificant value of the indicator, while the Trakia variety had significantly smaller. After the two-year storage, all varieties reacted with decrease in the values of the indicator compared to the one-year storage.

All variants of electromagnetic treatment had positive effect on the total length of the sprout and root with a shorter one-year storage period of the seeds (B×C). Compared to the control variant, one-year storage, untreated seeds, the total length of sprout and root was proved to be higher by 7.6% to 21.1% at variant 4. In case of the two-year storage period, this characteristic showed much lower values, compared to the one-year storage. At this storage period, all variants of treatment had positive effect of 2.3% to 11.0% at option 4 compared to the corresponding control.

The interaction of the three main factors determined significantly larger total length of sprout and root of the seeds only at the one year of storage compared to the accepted control Chirpan-539, one year of storage, untreated seeds. The highest values of this indicator were registered for the Natalia variety, processing options 1 and 4 - 22.9-24.1% over the control. Significantly greater total length of sprout and root was observed for the varieties: Helius, processing variants 2 and 4 - 19.5% and 16.5%; Nelina, options 2, 4 and 5 - 17.8-23.0% and Chirpan-539, option 4 - 15.3%. At these varieties, some treatment options showed higher values than the control variant, but the differences were insignificant. Higher but insignificant values were observed for the varieties: Chirpan-539, option 5; Helius, option 1; Natalia, option 2, Nelina, options 1 and 3. The total length of sprout and root was 11.2-14.1% over the control variant.

Regarding the two-year storage of the seeds, the total length of the sprout and root was significant and insignificantly shorter compared to the control variant. An exception was the Helius variety, in which at processing variants 1 and 4 this indicator had insignificantly higher values of 4.0-6.8% above the control.

Table 3. Effect of pre-sowing electromagnetic treatments on the total length of sprout and root of seeds stored for one and two years of 5 cotton varieties

Varieties	Treatments	Duration of storage		Interaction	In % to the
		1 year	2 years	A × B	control
Chirpan-539	1	22.763	18.597	20.680	102.4
	2	20.710	19.757	20.233	100.2
	3	22.623	21.503	22.063	109.3
	4	25.193	21.420	23.307	115.4**
	5	24.657	20.917	22.787	112.8*
	6	21.850	18.537	20.193	100.0
Interaction A × C		22.966	20.122	*Factor A* - 21.544	
Trakia	1	21.413	18.940	20.177	99.9
	2	21.993	19.797	20.895	103.5
	3	21.697	21.167	21.432	106.1
	4	22.713	19.343	21.028	104.1
	5	21.830	19.157	20.493	101.5
	6	18.450	17.880	18.165	89.9
Interaction A × C		21.349	19.381	*Factor A* - 20.365	
Helius	1	24.453	22.730	23.592	116.8**
	2	26.103	17.633	21.868	108.3
	3	21.020	19.083	20.052	99.3
	4	25.457	23.330	24.393	120.8***
	5	20.590	20.593	20.592	102.0
	6	18.143	19.867	19.005	94.1
Interaction A × C		22.628	20.539	*Factor A* - 21.584	
Natalia	1	26.847	19.540	23.193	114.9*
	2	24.300	19.013	21.657	107.3
	3	23.207	19.750	21.478	106.4
	4	27.117	20.467	23.792	117.8**
	5	22.263	20.293	21.278	105.4
	6	22.958	19.900	21.429	106.1
Interaction A × C		24.449	19.827	*Factor A* - 22.138	
Nelina	1	24.940	16.987	20.963	103.8
	2	25.747	17.283	21.515	106.5
	3	24.590	16.657	20.623	102.1
	4	26.873	16.907	21.890	108.4
	5	25.967	16.553	21.260	105.3
	6	23.773	15.237	19.505	96.6
Interaction A × C		25.315	16.604	*Factor A* - 20.959	
				Factor B	
Interaction B × C	1	24.083	19.359	21.721	110.5***
	2	23.771	18.697	21.234	108.0**
	3	22.627	19.632	21.130	107.5**
	4	25.471	20.293	22.882	116.4***
	5	23.061	19.503	21.282	108.3**
	6	**21.035**	18.284	**19.659**	**100.0**
Mean *Factor C*		23.341	19.295		

Total length of sprout and root

Errors at:	Factors						
	A	B	C	A × B	A × C	B × C	A × B × C
p<0.05	0.949	1.039	0.600	2.325	1.342	1.471	3.289
p<0.01	1.255	1.375	0.793	3.074	1.775	1.944	4.348
p<0.001	1.618	1.722	1.023	3.963	2.288	2.506	5.604

General mean: 21.439; Coefficient of variation: 9.49; Accuracy indicator: 5.48

*Factors: A- Varietiy; B- Electromagnetic treatment; C- Duration of storage of seeds before their electromagnetic treatment; 1, 2, 3, 4, 5 and 6 - applied treatment options, see Table 1.

When compared with the controls corresponding to each variety and storage period, all electromagnetic treatments had positive effect for the Trakia and Nelina varieties, at both storage terms. The Trakia variety reacted more strongly, at the shorter storage period the total length of sprout and root was greater by 16.1-23.1% than the respective control, and the best option was 4 (Figure 2). At the two-year duration of storage, the increase to the respective control was 5.9-18.4% at variant 3. For the Nelina variety the total length of sprout and root, in both storage periods, increased by 4.9-13.0% and 8.6-13.4%, respectively.

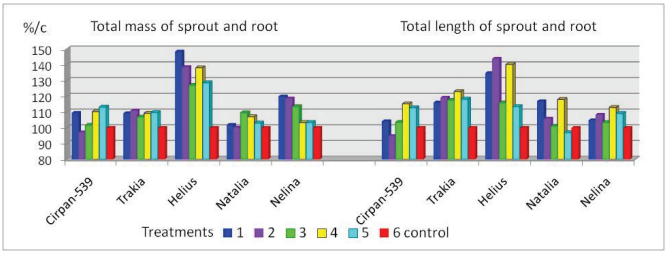

Figure 2. Effect of electromagnetic treatments on the total length and total mass of root and sprout of cotton seeds of 5 Bulgarian varieties, compared to the untreated corresponding control - option 6, with one-year storage of seeds before treatment

For the Chirpan-539 variety, positive effect of some treatments was also observed in the two storage periods. In case of one-year storage, variants 1, 3, 4 and 5 had positive effect of 3.5-15.3% at variant 4. In case of two-year storage, variants 2, 3, 4 and 5 had positive effect of 6.6-16.0% over the relevant control. The best variants were options 3 and 4 - 16.0% and 15.5%, respectively. The strongest stimulating effect of electromagnetic treatments was observed for the variety Helius, with one year of seed storage – 13.5-43.9% over the respective control. The best treatment options were 1 - 34.8%, 2 and 4 - 43.9% and 40.3%. In case of two-year storage, variants 1 and 4 had positive effect of 14.4-17.4% over the control. For the Natalia variety, positive effect of the electromagnetic treatments was reported only in case of the shorter storage period, as at options 1 and 4 the total length of the sprout and root was increased by 16.9% and 18.1%.

The best treatment option was 4, which could be applied to all varieties, with both storage terms. According to Table 1, option 4 had the low values of the controllable factors - voltage and duration of influence (starting with 6 kV and 5 s) of the electromagnetic energy.

As for the Helius variety, in case of one-year storage of the seeds, variant 2 could be used and regarding the Chirpan-539 and Trakia varieties, in case of two-year storage of the seeds, variant 3 could be used.

Total mass of sprout and root

Of the varieties, as an independent factor, Trakia, Helius, Natalia and Nelina had smaller total mass of sprout and root than Chirpan-539 accepted for control (Table 4). All variants of pre-sowing electromagnetic treatment of seeds as individual factor had significant positive effect. The seeds treated in electromagnetic field formed larger total mass of the sprout and root and exceeded the control variant by 7.8-12.7%. Processing options 1 and 4 were the best (Figure 1). The two-year storage of seeds showed lower total mass of the sprout and root compared to the one-year storage.

As a result of the interaction of cultivars × treatments, the largest total mass of the sprout and root was reported for the Chirpan-539 variety, at variant of treatment 5, by 12.9% above the control variant Chirpan-539, untreated seeds. At treatment variant 1, the increase in total mass was 9.8%. Weaker, by 2.5 to 6.2% and insignificant was the increase in total mass of the sprout and root in the other treatment options - by 2.5 to 6.2%.

For the Helius variety and treatment variant 1, the total mass of the sprout and root was proven to be higher by 10.0% than the control, and at variant 4 insignificantly higher by 8.9%. At the other variants this indicator was equal to the control, the differences were insignificant. For the other varieties, the effect of the electromagnetic treatments showed equalization with the control variant or proven lower results.

All varieties, with the exception of Nelina variety and one-year of storage, after one- and two-year storage of seeds, had significantly lower total mass of the sprout and root than the control variant Chirpan-539 variety, one year of storage (A×C). For the Chirpan-539 and Trakia varieties, after the two-year storage of the seeds, the total mass of sprout and root was insignificantly smaller than their one-year storage, while for the Helius variety it was insignificantly higher. For the other two varieties, this character had significantly lower values in the longer two-year period compared to the shorter one-year storage period.

As a result of the interaction of treatments × duration of storage, all variants of pre-sowing electromagnetic treatment had greater stimulating effect on seeds stored for one year. The total mass of the sprouts and roots was higher by 10.8-16.5% than the control variant one year of storage, untreated seeds. The best treatment option was 1.

Concerning seeds stored for two years, higher but insignificant values compared to the control variant were observed at options 1, 3 and 4. In their two-year storage under the influence of the electromagnetic impact the total mass of the sprout and root was increased by 4.5-9.1% at option 4, compared to the corresponding to this storage term control variant.

As a result of the interaction of the three main factors, the highest total mass of sprout and root was observed for the Nelina variety, for the seeds stored for one year and processing options 1, 2 and 3. The total mass of sprout and root was proven to be higher by 12.3-18.7% than the control variant Chirpan-539 variety, without processing and one-year storage, as the best option was 1. Higher total mass of the sprout and root - by 13.2% - was observed for the Chirpan-539 variety, after one-year storage and treatment variant 5. At the same variety, variants 1 and 4, the seeds stored for one year had 9.5-10.3% higher total mass of the sprout and root, and for the seeds stored for two years, at variants 1, 3 and 5 this increase was by 6.1-8.4%, but the differences were insignificant.

Table 4. Effect of pre-sowing electromagnetic treatments on the total mass of sprout and root of seeds stored for one and two years of 5 cotton varieties

Varieties	Treatments	Duration of storage		Interaction	In % to the
		1 year	2 years	A × B	control
Chirpan-539	1	0.613	0.594	0.604	109.8*
	2	0.544	0.583	0.564	102.5
	3	0.566	0.601	0.584	106.2
	4	0.618	0.523	0.571	103.8
	5	0.634	0.607	0.621	112.9**
	6	**0.560**	0.541	**0.550**	**100.0**
Interaction A × C		0.589	0.575	*Factor A* – 0.582	
Trakia	1	0.551	0.529	0.540	98.2
	2	0.559	0.519	0.539	98.0
	3	0.539	0.540	0.540	98.2
	4	0.551	0.552	0.551	100.7
	5	0.553	0.568	0.560	101.8
	6	0.504	0.509	0.507	92.2
Interaction A × C		0.543	0.536	*Factor A* – 0.510	
Helius	1	0.615	0.595	0.605	110.0*
	2	0.574	0.501	0.537	94.0
	3	0.526	0.565	0.546	99.3
	4	0.572	0.625	0.599	108.9
	5	0.533	0.541	0.537	97.6
	6	0.414	0.508	0.461	83.8000
Interaction A × C		0.539	0.556	*Factor A* – 0.547	
Natalia	1	0.528	0.476	0.502	91.3
	2	0.519	0.487	0.503	91.5
	3	0.568	0.474	0.521	94.7
	4	0.555	0.499	0.527	95.8
	5	0.534	0.460	0.497	90.40
	6	0.518	0.492	0.505	91.8
Interaction A × C		0.537	0.481	*Factor A* – 0.509	
Nelina	1	0.665	0.441	0.553	100.5
	2	0.658	0.453	0.555	100.9
	3	0.629	0.413	0.521	94.7
	4	0.573	0.452	0.513	93.3
	5	0.571	0.371	0.471	85.600
	6	0.554	0.378	0.466	84.700
Interaction A × C		0.608	0.418	*Factor A* – 0.513	
				Factor B	
Interaction B × C	1	0.594	0.527	0.561	112.7***
	2	0.571	0.508	0.540	108.4***
	3	0.566	0.519	0.542	108.8***
	4	0.574	0.530	0.552	110.8***
	5	0.565	0.509	0.537	107.8***
	6	**0.510**	0.486	**0.498**	**100.0**
Mean *Factor C*		0.563	0.513	-	-

Total mass of sprout and root

Errors at:	Factors						
	A	B	C	A × B	A × C	B × C	A × B × C
p<0.05	0.021	0.022	0.013	0.050	0.029	0.031	0.071
p<0.01	0.027	0.030	0.017	0.066	0.038	0.042	0.094
p<0.001	0.035	0.038	0.022	0.086	0.049	0.054	0.121

General mean: 0.540; Coefficient of variation: 8.14; Accuracy indicator: 4.70

*Factors: A- Varietiy; B- Electromagnetic treatment; C- Duration of storage of seeds before their electromagnetic treatment; 1, 2, 3, 4, 5 and 6 - applied treatment options, see Table 1.

For the Helius variety, in the case the seeds were stored for one year, larger but insignificant total mass of sprout and root by 9.8% was observed at option 1, and in the case the seeds were stored for two years – in options 1 and 4 - by 6.3-11.6%.

When compared with the controls corresponding to each variety and storage period, the greatest stimulating effect of electromagnetic treatment was observed for the Helius variety, for seeds stored for one year. The total mass of the sprout and root was increased at all treatment variants, from 27.1% to 48.5% (Figure 2).

The best variants were 1, 2 and 4, in which the increase was by 38.2-48.5% at variant 1. After the two-year storage of seeds, processing options 1, 3, 4 and 5 had positive effect and the total mass of the sprout and root was increased from 6.5% to 23.0% in option 4.

Stimulating effect of pre-sowing electromagnetic treatments was observed for the other varieties, in both storage periods. As for the Nelina variety, variants 1, 2 and 3 were the best at the one-year storage of the seeds, and at the two-year storage these were variants 1, 2 and 4 as the total mass of the root and sprout was increased by 13.5-20.0% and 16.7-19.8 %.

For the Chirpan-539 variety, the effect of electromagnetic treatments expressed in higher total mass of the sprout and root was by 9.5-13.2% in case of the one year of storage, at options 1, 4 and 5, and by 7.8-12.2% in case of the two years storage, at options 1, 2, 3 and 5. Option 5 was the best for both storage periods.

The obtained results for the total length and total mass of the root and sprout confirmed the positive energy impact on the sowing qualities of the seeds, established by other authors in other crops. Palov et al. (2013b) reported 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. Bilalis et al. (2012b, 2013) reported the germination of cotton seeds was increased, the plant growth in the early stage was accelerated and the accumulation of chemical elements was also improved. Similar results were obtained by other authors, for increasing yields and an earlier maturation of cotton (Stoilova et al., 2011). Đukić et al. (2017) also reported that exposures 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. Research results depended, however, on the frequency, duration of exposure, seed traits and plant species (Cruz et al., 2011; Sedighi et al., 2013). Sirakov et al. (2021) concluded that as a result of the studies with an appropriate combination of the controllable factors an opportunity was found to stimulate to a different extent 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. In our study, the Helius variety showed a very strong increase in total length (34.8-43.9%) and total mass (48.5%) of sprout and root during one year of seed storage.

In the case of stored cotton seeds, for a period of one and two years, the pre-sowing electromagnetic treatment, with the selected values of the controllable factors, stimulated the development of the primary root system and thus greatly improved their biological value. In many cases, the parameters of the studied characteristics of the electromagnetically treated seeds, for most of the applied doses, were better than the control values of untreated seeds. The results of this study also show that electromagnetic treatments improved the development of the primary root system of sufficiently long-stored seeds.

The achieved results could be used in conventional and organic agriculture, to stimulate the growth and development of the primary root system of stored (reserve) seeds for sowing and of conserved seeds from genetic resources with impaired sowing qualities.

Conclusion

Based on the results obtained, the following conclusions can be drawn: 1) Pre-sowing electromagnetic treatments of cotton seeds, stored one and two years before treatments, had stimulating effect on the total length and total mass of sprout and root: the total length of sprout and root increased by 7.5-16.4% ($p<0.05$); the total mass of sprout and root increased by 7.8-12.7% ($p<0.05$). Processing options 1[U= (8…5)kV, τ= (15…35)s] and 4[U= (6…3)kV, τ= (5…25)s] appeared to be the best. 2) Compared to the untreated control corresponding to each storage period, the electromagnetic impact had stimulating effect for both storage periods: for the total length of sprout and root by 7.6-21.1% and 2.3-11.0% at option 4; for the total mass of sprout and root by 10.8-16.5% at option 1 and 4.5-9.1% at option 4, respectively, at one-year and two-year storage of seeds. 3) In comparison with the control Chirpan-539 variety, untreated seeds, one-year storage, higher values for both studied characteristics were found only for seeds stored for one-year. 4) Compared to the untreated control corresponding to each cotton variety and storage term stimulating effect of the pre-sowing electromagnetic treatment for both characteristics was found for all varieties, for both storage periods. 5) The most responsive to the electromagnetic impact proved to be the variety Helius with the strongest stimulating effect for both characteristics, at one-year storage of seeds the total length of sprout and root increased most strongly by 34.8-43.9% at options 1, 2 and 4 and the total mass of sprout and root increased by 48.5% at option 1.

References

Aguilar JO, Rivero DS, Puentes AE, Perilla PEV and Navarro AMS, 2015. Comparison of the effects in the germination and growth of corn seeds (*Zea Mays* L.) by exposure to magnetic, electrical and electromagnetic fields.

Chemical Engineering Transactions, 43, 169-174. https://doi.org/10.3303/CET1543029

Alvarez J, Carbonell MV, Flórez M, Martínez E and Campos A, 2012. Study of 125 mT magnetic treatment on the germination and initial growth of triticale seeds. Scientific works of the University of Ruse, 51, series 3.1, 163-167.

Antonova G, Mihov M, Sirakov K, Zahariev St and Palov Iv, 2013. Study of the effect of pre-sowing electromagnetic treatment on the germination of cabbage seeds. Agricultural Engineering, 1, 22-26 (Bg).

Antonova G, Mihov M, Decheva S, Sirakov K, Zahariev Sv and Palov Iv, 2014. Influence of pre-sowing electromagnetic treatment on some main characters of economic characteristic of head cabbage. Turkish Journal of Agricultural and Natural Sciences, 2, 1574-1578.

Antonova G, Boteva Hr, Sirakov K and Palov Iv, 2018. Influence of pre-sowing electromagnetic treatment of pepper seeds on the biometric indicators of seedlings. In: Proceedings of national scientific conference with international participation "Ecology and Health", Plovdiv, Bulgaria, pp. 47-52, ISSN 2367-9530. http://hst.bg/bulgarian/conference.htm

Antonova-Karacheva G and Sirakov K, 2020. Results of the pre-sowing electromagnetic treatments of seeds from Bulgarian pepper variety. New knowledge Journal of science, 9(1), 109-114.

Bilalis D, Katsenios N, Efthimiadou A and Karkanis A, 2012a. Pulsed electromagnetic field: an organic compatible method to promote plant growth and yield in two corn types. Electromagnetic Biology and Medicine, 31, 333-343.

Bilalis D, Katsenios N, Efthimiadou A, Karkanis A and Efthimiadis P, 2012b. Investigation of pulsed electromagnetic field as a novel organic pre-sowing method on germination and initial growth stages of cotton. Electromagnetic Biology and Medicine, 31,143-150.

Bilalis D, Kamariari PE, Karkanis A, Efthimiadou A, Zorpas A and 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, 190-194.

Bozhkova Yu, Palov Iv and Stefanov St, 1993. Influence of the pre-sowing electromagnetic treatment on the properties of cotton seeds. Agricultural engineering, 30, 3-7 (Bg).

Cruz DG, Bautista RZ, Aguilar CH, Pacheco FAD, Orea AC and Bonilla JLL, 2011. Physical characteristics of grain of maize presowing treated by electromagnetic fields. Acta Agrophysica, 18, 17-31.

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

Flórez M, Martínez E, Carbonell MV, Álvarez J and Campos A, 2014. Germination and initial growth of triticale seeds under stationary magnetic treatment. Journal of Advances in Agriculture, 2, 72-79.

Ganeva D, Mihov M, Palov Iv, Sirakov K and Zahariev St, 2013. Results of laboratory tests after pre-sowing electromagnetic treatment of seeds of Bulgarian tomato varieties. Agricultural Engineering, 3, 13-21 (Bg).

Ganeva D, Sirakov K, Mihov M, Martev K, Zahariev S and Palov I, 2014. Influence of pre-sowing electromagnetic treatments on propagating seed qualities of tomato variety Milyana. In: Proceeding of the International Symposium, ISB-INMA TEH' 2014, "Agricultural and Mechanical Engineering", Bucharest, Romania, pp. 646-653.

Iqbal M, Muhammad D, Jamil Y and Ahmad MR, 2012a. Effect of pre-sowing magnetic field treatment to garden pea (*Pisum sativum* L.) seed on germination and seedling growth. Pakistan Journal of Botany, 44, 1851-1856.

Iqbal M, Haq ZU, Jamil Y and Ahmad MR, 2012b. Effect of presowing magnetic treatment on properties of pea. International Agrophysics, 26, 25-31.

Koleva M and Radevska M, 2020. Effect of electromagnetic treatment on the sowing qualities of cotton seed. Academic Publishing House of the Agricultural University – Plovdiv, p. 172, ISBN 978-954-517-293-9.

Kostov K, Palov Iv, Sirakov K, Kuzmanov E and Zahariev Sv, 2014. Effect of pre-sowing electric treatments of seeds on the yields of wheat varieties Enola and Kristy. Bulgarian Journal of Agricultural Science, 20, 1508-1512.

Martinez E, Florez M and Carbonell MV, 2017. Stimulatory effect of the magnetic treatment on the germination of cereal seeds. International Journal of Environment, Agriculture and Biotechnology (IJEAB), 2, 375-381.

Muhova A, Sirakov K, Stoilova A, Stefanova-Dobreva St and Palov Iv, 2016. Study the effects of pre-sowing electromagnetic treatment of some laboratory parameters on triticale seeds. World Science, No 10(14), October 2016, 40-45. https://rsglobal.pl/index.php/ws/issue/view/56/56

Palov Iv, Stefanov St, Sirakov K, Bozhkova Yu and Valkova N, 1994. Possibilities of the pre-sowing electromagnetic treatments of cotton seeds. Agricultural Engineering, 31, 3-6 (Bg).

Palov Iv, Stefanov St, Ganev Hr, Zlatev Zl and Stankovski M, 1995. Method for pre-sowing electromagnetic treatment of peanut seeds. Patent for Invention, No. 42681, A 01 C 1/00, A 01 C 7/04, Sofia, Bulgaria.

Palov Iv, Genchev Sq, Sirakov K, Zahariev St and Kuzmanov E, 2013a. Results of field studies after pre-sowing electromagnetic treatments of French corn hybrid seeds. Mechanization in agriculture & Conserving of the resources, 59, 32-34 (Bg).

Palov Iv, Sirakov K, Kuzmanov E and Zahariev Sv, 2013b. Results of preliminary laboratory studies after pre-sowing electric treatment of pea seeds. Agricultural engineering, Belgrade, Serbia, No. 4, 17-23.

Palov I, Stoilova A, Sirakov K and Zahariev S, 2016. Possibilities for increasing the yields after pre-sowing electric treatment of wheat and maize seeds. World Science, No 3(7), Vol. 3, March 2016, 6-13. https://rsglobal.pl/index.php/ws/issue/view/24/24

Pietruszewski St and Martínez El, 2015. Magnetic field as a method of improving the quality of sowing material: A review. International Agrophysics, 29, 377-389. doi: 10.1515/intag-2015-0044.

Radhakrishnan R and Kumari RBD, 2012. Pulsed magnetic field: a contemporary approach offers to enhance plant growth and yield of soybean. Plant Physiology and Biochemistry, 51, 139-144.

Sedihi NT, Abedi M and Hosseini SE, 2013. Effect of electric field intensity and exposing time on some physiological properties of maize seed. European Journal of Experimental Biology, 3(3), 126-134.

Sirakov K, 2015a. Modeling of the electric field of an electrode system for pre-sowing electromagnetic treatments of vegetable seeds. In: Proceeding of the International Scientific Conference - Energy efficiency and agricultural engineering, Ruse, Bulgaria, pp. 224-228.

Sirakov K, 2015b. Modelling the electric field between a point-to-working chamber electrode system for pre-sowing treatment of seeds of vegetable crops. In: Proceeding of the 14th International Conference on Electrical Machines, Drives and Power Systems "ELMA 2015", Varna, Bulgaria, pp. 223-226, ISSN 1313-4965.

Sirakov K, 2020a. Study on the electric field between the electrodes of a chamber for pre-sowing treatment of seeds. In: Proceeding of the 7th International Conference on Energy Efficiency and Agricultural Engineering (EE&AE), Ruse, Bulgaria, pp.1-3. doi: 10.1109/EEAE49144.2020.9279054

Sirakov K, 2020b. Optimization of the design of a chamber for pre-sowing treatment of seeds. In: Proceeding of the 7th International Conference on Energy Efficiency and Agricultural Engineering (EE&AE), Ruse, Bulgaria, 1-3. doi: 10.1109/EEAE49144.2020.9279024

Sirakov K, Antonova G, Zahariev St, Decheva S, Palov Iv and Mihov M, 2013. Influence of pre-sowing electromagnetic treatment on the growth force of head cabbage seeds. Agricultural Engineering, 2, 12-18 (Bg).

Sirakov K, Ganeva D, Mihov M, Martev Kr, Zahariev Sv and Palov Iv, 2014. Investigation of the influence of the pre-sowing electromagnetic treatment and the storage time on the sowing qualities of tomato seeds of the Miliana variety. Agricultural Engineering, 3-4, 16-24 (Bg).

Sirakov K, Ganeva D, Zahariev St, Palov Iv and Mihov M, 2015. Results of study of the influence of pre-sowing electromagnetic treatments and storage time on the germination of seeds of Bulgarian tomato varieties. Ecology and Future, Sofia, 1-2, 65-71 (Bg).

Sirakov K, Ganeva D, Zahariev S, Palov Iv and Mihov M, 2016a. Study of laboratory germination of seeds from tomato variety Milyana after electromagnetic treatment. INMATEH - Agricultural Engineering, Bucharest, Romania, Vol. 48, No 1, 53-60. e ISSN: 2068-2239, p ISSN: 2068-4215.

Sirakov K, Stoilova A, Muhova A, Palov Iv and Stefanova-Dobreva S, 2016b. Study the effect of pre-sowing electromagnetic treatments on laboratory germination vigor and germination of seeds of Bulgarian triticale varieties. World Science, 10(6), 31-40.
https://rsglobal.pl/index.php/ws/issue/view/56/56

Sirakov K, Palov Iv, Stoilova A and Muhova A, 2016c. Studying the effect of presowing electromagnetic treatment on the lengths of roots and sprouts of triticale seed cultivar Respect. In: Proceedings of University of Ruse "Angel Kanchev", 55, b.3.1, Ruse, Bulgaria, pp. 83-93, ISBN 1311-3321.

Sirakov K, Stoilova A, Palov Iv and Muhova A, 2018. Studying the effect of pre-sowing electromagnetic treatment on the lengths of roots and sprouts of triticale seeds the cultivar Boomerang. World Science, 1(2), 10-17. https://www.researchgate.net/publication/330441449_STUDYING_THE_EFFECT_OF_PRE-SOWING _ELECTROMAGNETIC_TREATMENT_ON_THE_LENGTHS_OF_ROOTS_AND_SPROUTS_OF_TRITICALE_SEEDS_THE_CULTIVAR_BOOMERANG

Sirakov K, Álvarez J and Muhova A, 2021. Evaluation of the effect of electromagnetic treatment on the sowing qualities of triticale seeds. Bulgarian Journal of Agricultural Science, 27, 699-711.

Stoilova A, Palov Iv, Sirakov K and Radevska M, 2011. Results from the study of pre-sowing electromagnetic treatments of seeds of Bulgarian cotton varieties. Ecology, genetics, selection in the service of mankind. In: Proceedings of the International Scientific Conference, GNU Ulnovsky NIISH Timiryazevsky Rosselkhozakademii (June 28-30, 2011), pp. 374-382 (Ru).

Terziev P, Palov Iv, Stefanov St and Radev R, 1995. Device for pre-sowing electrical treatment of seed material. Patent Holders No 30631, A 01C 1/100, A01 N 21/00, INRA, Sofia, Bulgaria.

Zahariev Sv, 2014. Modelling of the electric field arising in a device for pre-sowing electromagnetic treatment of the seeds of cereal grains with the device full of seeds. National Scientific Conference with International Participation, Tg-Jiu, Romania, 3, pp. 195-198.

Zahariev Sv, 2015. Optimization of pre-sowing electric treatment of seeds. Thesis for PhD (scientific fields "Electricity supply and electrical equipment" and "Mechanization and electrification of crop production"), Faculty of Electrical Engeneering Electronics and Automation, "Angel Kanchev" University of Ruse, Ruse, Bulgaria (Bg).

Zahariev Sv, Sirakov K, Palov Iv and Kuzmanov E, 2013. Results of laboratory tests after pre-sowing electromagnetic treatments of seeds of French corn hybrid. Mechanization of Agriculture, Sofia, 1, 29-31 (Bg).

Zahariev Sv, Streblau M and Sirakov K, 2014. Computer modelling of the electric field arising in a device for pre-sowing electromagnetic treatment of the seeds of cereal grains. National Scientific Conference with international participation, Tg-Jiu, Romania, 3, 187-191.