Influence of duration of storage and pre-sowing electromagnetic treatment on the sowing qualities of cotton seeds

II. Sprout and root length

Minka Koleva*, Milena Radevska
Field Crops Institute, 6200 Chirpan, Bulgaria
*E-mail: *m_koleva2006@abv.bg*

Citation
Koleva, M., & Radevska, M. (2021). Influence of duration of storage and pre-sowing electromagnetic treatment on the sowing qualities of cotton seeds. II. Sprout and root length. *Rastenievadni nauki, 58*(6) 68-74.

Abstract
Seeds of five Bulgarian cotton varieties Chirpan-539, Helius, Trakia, Natalia and Nelina, stored for one and two years, were subjected to pre-sowing electromagnetic treatments. It was found stimulating effect of treatments on the length of sprout (10.1-15.3%), length of root (5.3-17.5%) and total sprout and root length (7.5-16.4%). The sprout length was most strongly influenced by the varieties × duration of storage interaction, while the root length and total sprout and root length were most strongly influenced by the duration of storage. Compared to the control variant - Chirpan-539, untreated seeds, stored for one year, greater total sprout and root length was accounted at the one-year storage of seeds for the varieties: Natalia, treatment options 1[U=(8…5)kV, τ =(15…35)s] and 4[U=(6…3)kV, τ =(5…25)s] - 22.9-24.1%; Nelina and Helius, treatment options 2 and 4 – respectively 17.8-23.0% и 16.5-19.5%. The strongest stimulating effect of the treatments on the total sprout and root length was observed for the Helius variety for the seeds stored for one year and treatment option 2[U=(6…3)kV, τ = (15…35) s] - 43.9% compared to the corresponding of these varieties control (untreated seeds, one year storage).

Key words: pre-sowing electromagnetic treatment; cotton seeds; sprout length; root length; total sprout and root length

INTRODUCTION

Seeds are the main reproductive structure of plants. Properly stored, seeds can remain viable for a long enough time. But even when seeds were stored under optimal conditions, their viability decreased as a result of the aging process, which is a physiological and genetically determined, and is individual for each plant species and variety (Sastry et al., 2008). The use of seeds with impaired sowing qualities has a negative effect on the germination and viability, which can compromise the germination and lead to crops with uneven density and development, leading to 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 the genetic potential for yield and high quality of production.

The growing need for an organic agricultural product, together with the increase in plant material for food production, necessitates the search for new, safer factors to increase production, given not only the application of traditional methods using fertilizers and agrochemicals, but also through the use of environmentally friendly techniques.

The use of different types of magnetic fields (Vashisth & Nagarajan, 2010; Aladjadjiyan & Ylieva, 2003) is increasingly used in modern agriculture because they have a minimal impact on the environment and at the same time contribute to increased productivity.

The impact of magnetic fields on cotton seeds has been studied. Electromagnetic fields have been found to increase germination and improve the early growth characteristics of cotton (Bilalis et al., 2012). The pre-sowing treatment of cotton seeds 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 weight of sprouts and roots of onion (Alexander & Doijode, 1995), maize (Aladjadjiyan, 2002), rice (Florez et al. 2007), chickpeas (Vashisth & Nagarajan, 2008).

The aim of this research was to study the effect of pre-sowing electromagnetic treatment on the length of root and sprout of cotton seeds have stored for 1 and 2 years.

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 have been 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. 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. It is also special that 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 the table was also set. Such pre-sowing electromagnetic treatment was most effective for the seeds of "Ogosta" cotton variety.

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 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. 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 of the environment 95%. The length 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 ANOVA 123 program was used. The factors of experience were:

A – Varieties;

B – Electromagnetic treatments;

C – Duration 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)					

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 corresponding to each variety controls.

RESULTS AND DISCUSSION

The growth strength of the primary root and sprout is an expression of the seed sowing qualities within the respective variety. The data from the biometric measurements on the length of root and sprout growth and their mass make it possible to assess the reaction of the tested varieties in the initial stages of their development.

The strength of the influence of the main factors and the interactions between them on the studied characteristics was established after the analysis of the variance.

The analysis of the variance of the sprout length showed that the interaction of varieties × duration of storage had the strongest influence - 26.03% on the formation of this indicator (Table 2). Of the three independent factors, the duration of storage had the greatest impact - 21.79%, the treatments had the weakest impact. The interaction of treatments × duration of storage was significant, but was of low weight. The interaction of varieties × treatments and the interaction of the three main factors were insignificant.

The analysis of the variance of the root length showed that the duration of storage had the strongest impact on its formation - 35.95% (Table 2). The other two main factors - varieties and electromagnetic treatments had very weak significant effect. The influence of all interactions was significant. The interaction of varieties × treatments and the interaction of the three main factors varieties × treatments × duration of storage proved to be the most important.

The strongest influence on the formation of the total length of the root and sprout similarly was found for the duration of storage - 35.5% (Table 2). This means that the seeds of the two storage periods (one- and two-year) differed significantly in this indicator. Varieties and treatments, as independent factors, had significant, but very weak impact. The influence of the interaction of varieties × treatments was insignificant, which means that the varieties reacted similarly to the treatments. Of the other three interactions, which were significant, the varieties × duration of storage had the greatest weight. This means that the varieties responded differently to storage in terms of total length of root and sprout.

The results for the independent action of the three main factors on the studied indicators are presented in Figure 1. Of the varieties, as an individual factor, Chirpan-539, Natalia and Helius had the largest sprout length, while the other two Trakia and Nelina had significantly shorter sprout length (Fig. 1a). The largest root length and the largest total length of the root and sprout were found for the variety Natalia. The Helius variety was equal to it. The Trakia variety showed sig-

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 of duration of 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

nificantly smaller total length of the root and sprout, Nelina variety showed insignificantly smaller one.

All variants of electromagnetic treatments had a positive effect on the observed indicators. Sprout length increased by 10.2-15.3%, root length increased by 5.3-17.5%, and the root and sprout total length increased by 7.5-16.4% compared to control untreated seeds. Of the treatments, variants 1 and 4 had the greatest impact on the length of sprout and root and their total length (Fig. 1b).

Seeds have stored for two years had shorter sprout length and root length and total sprout and root length, respectively, compared to seeds have stored for one year (Fig. 1c).

As a result of the interaction of the factors varieties × treatments, the greatest sprout length was observed for the varieties Helius, variants 1 and 4, Chirpan-539 and Natalia, variant 1. The sprout length was greater by 11.7-17.1% compared to the control untreated variant of Chirpan-539 variety, have stored for one year. The variety Helius, variants 1, 2 and 4, and the variety Trakia, variants 3, 4 and 5, showed the strongest increase in the sprout length compared to its own untreated control.

The interaction A × B (varieties × treatments) determined significantly longer root length by 16.4-23.6% for the varieties Chirpan-539, at treatment variants 4 and 5, Helius and Natalia, variants 1 and 4, Nelina, variant 4, in comparison with Chirpan-539 variety, untreated seeds, one year duration of storage. The Chirpan-539 and Helius varieties reacted strongest at treatment variant 4, their root lengths were greater by 21.2% and 23.1%, compared to the corresponding control for the variety. As for the Natalia and Nelina varieties, also at treatment variant 4, the root length was higher by 11.6% and 17.2%, for the Trakia variety, at options 3 and it was higher by 16.2%, compared to the respective controls.

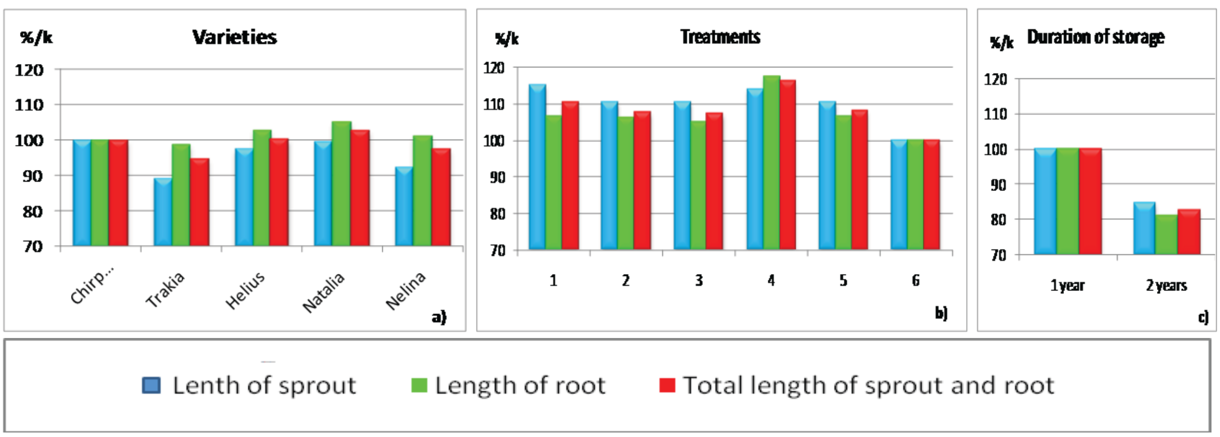

Figure 1. Independent action of the main factors – varieties (a), pre-sowing electromagnetic treatments (b) and duration of storage (c) on the length of sprout, length of root and total length of sprout and root

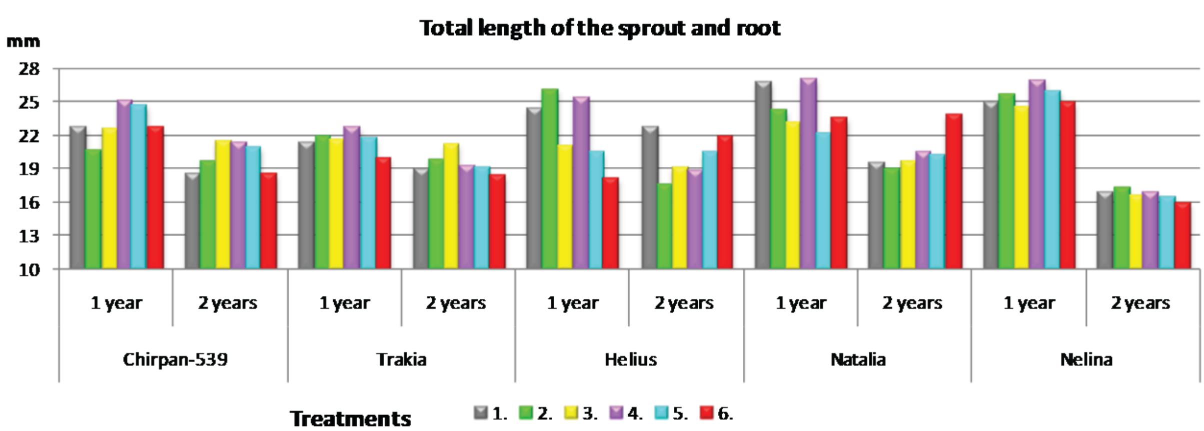

Figure 2. Interaction of factors varieties × treatments × duration of storage (A × B × C) on the total length of the sprout and root

As a result of the interaction of varieties × duration of storage, the varieties Nelina and Natalia had the longest sprout length with one-year storage, respectively by 11.1% and 7.7% above the control variant Chirpan-539, one year of storage. In the two-year storage period, the sprout length was significantly shorter than the one-year storage.

Variety Natalia at one-year storage had significantly longer root length by 10.4% of the control variant untreated seeds of variety Chirpan-539, untreated seeds and one-year storage. For the other varieties, with a shorter term of storage of one year, the differences were insignificant. In the two-year storage of seeds, the length of root was significantly shorter than the control variant and their one-year storage.

As for the seeds have stored for one year, all variants of electromagnetic treatment (the interaction of treatments × duration of storage) had a positive effect on the length of the sprout and root. At the treatment variants 1 and 4 the sprout length was 18.0-18.6% above the control - untreated seeds of Chirpan-539 variety and one year storage term, on the root length significant stimulating effect from 8.3% to 22.8% above the control was found for the options 1, 2, 4, and 5, option 4 was the best.

Seeds stored for two years, for all varieties and electromagnetic treatments, had significant shorter length of sprout and root, compared to the control variant – Chirpan-539 variety, untreated seeds, one-year storage.

As a result of the interaction of the three main factors, longer sprout length by 15.7-21.5% over the control variant (Chirpan-539 variety, one-year storage, untreated seeds) was found for the Helius, Natalia and Nelina varieties. The Helius and Trakia varieties reacted most strongly positively to electromagnetic treatment and all treatment variants gave positive effect in both storage periods, compared to the corresponding to each variety control. For the Helius variety, in case of one-year storage, processing options 1, 2 and 4 were the best, in case of two-year storage this was option 4, in which the length of sprout was increased by 44.5-48.8% and 27.4%.

For the Trakia variety, in case of one-year storage, variants 3 and 4 were the best, in case of two-year storage these were the variants 3 and 5, and the increase in the length of sprout was 22.4-23.0% and 19.0-21.3%. Significantly longer root length by 17.6-30.5% over the control variant was found for the varieties Chirpan-539, treatment option 4, Helius, option 2, Natalia, options 1 and 4 and Nelina, options 4 and 5, in the case of seeds have stored for one year. The stimulating effect was most pronounced for the Nelina variety, treatment option 4. Compared to the respective controls, positive effect was observed for all varieties, during both storage periods.

In case of one-year storage of seeds, the pre-sowing electromagnetic treatment stimulating effect was most pronounced for the Helius variety, treatment variants 2 and 4, the root length was increased by 36.5% and 43.5%, respectively, compared to the respective control. Processing variant 4 proved to be the best for all varieties. In case of two-year storage, the stimulating effect was most pronounced for the variety Chirpan-539, options 3, 4 and 5 - 16.7-25.8% at the treatment variant 4. Treatment option 4 could be applied in case of two-year storage of seeds for all varieties.

The interaction varieties × treatments had the greatest influence on the total length of the sprout and root. The varieties reacted differently to the two seed storage periods in terms of total sprout and root length. At the one-year storage, the highest indicators were recorded for the varieties Nelina and Natalia by 10.2% and 6.5%, respectively, above the control - Chirpan-539, one year of storage. At the two-year storage, all varieties had a significant shorter total length of sprout and root than the control and all varieties reacted with a decrease of the this indicator in comparison with their one-year storage.

The interaction of treatments × duration of storage determined a greater total length of sprout and root by 7.6% to 21.1% at the one-year storage of seeds, compared to the control. Treatment option 4 was the best. After the two-year storage, all treatment variants showed significant and insignificant lower values than the control variant.

As a result of the interaction of the three main factors significant greater total length of sprout and root compared to the control Chirpan-539, untreated seeds and one year storage, was reported after the one-year storage of the varieties: Natalia, treatment options 1 and 4 - 22.9 -24.1%; Nelina and Helius, treatment options 2 and 4 - respectively 17.8-23.0% and 16.5-19.5%; Chirpan-539, treatment variant 4 - 15.3%. The Trakia and Nelina varieties reacted positively to all electromagnetic treatments in regard to the two storage periods, compared to the corresponding controls. The effect of the treatments was greater for the variety Trakia - 16.1-23.1% and 5.9-18.4%, respectively after the one-year and two-year storage of seeds. Chirpan-539 variety also reacted

Table 3. Effect of pre-sowing electromagnetic treatment on the length of sprout and length of root of seeds of 5 cotton varieties after one-year and two-year storage of seeds

Varieties	Treatments	Length of sprout, mm				Length of root, mm			
		Duration of storage		Interaction A×B	In % to control	Duration of storage		Interaction A×B	In % to control
		1 year	2 years			1 year	2years		
Chirpan-539	1	9.71	9.77	9.74	111.7	13.05	8.83	10.94	95.3
	2	8.72	9.11	8.92	102.3	12.02	10.64	11.33	98.8
	3	9.29	9.57	9.43	108.1	13.34	11.94	12.64	110.1
	4	10.24	8.54	9.39	107.7	14.95	12.87	13.91	121.2^{++}
	5	9.85	9.12	9.49	108.8	14.90	11.80	13.35	116.4^{+}
	6	9.14	8.30	**8.72**	**100.0**	**12.72**	10.23	11.47	**100.0**
Interaction A×C		9.50	9.07	***Factor A* -** 9.28		13.50	11.05	***Factor A*** - 12.28	
Trakia	1	8.27	8.21	8.24	94.5	13.15	10.72	11.94	104.0
	2	8.30	8.34	8.32	95.4	13.69	11.46	12.58	109.6
	3	8.69	8.72	8.71	99.8	13.01	12.44	12.73	110.9
	4	8.73	8.24	8.49	97.3	13.98	11.10	12.54	109.3
	5	8.45	8.89	8.67	99.5	13.38	10.33	11.86	103.3
	6	7.10	7.73	7.21	82.7^{000}	11.35	10.55	10.95	95.5
Interaction A×C		8.26	8.29	***Factor*** A - 8.27		13.09	11.10	***Factor*** A - 12.10	
Helius	1	10.77	9.07	9.92	113.8^{+}	13.68	13.66	13.67	119.1^{++}
	2	10.46	7.68	9.07	101.8	15.65	10.02	12.84	111.9
	3	9.31	8.24	8.78	104.0	11.71	10.84	11.28	98.3
	4	10.57	9.86	10.21	117.1^{++}	14.89	13.47	14.18	123.6^{+++}
	5	8.85	8.66	8.76	100.4	11.74	11.93	11.84	103.2
	6	7.24	7.74	7.49	85.9^{0}	10.91	12.13	11.52	100.4
Interaction A×C		9.53	8.54	***Factor*** A - 9.04		13.10	12.00	***Factor*** A - 12.55	
Natalia	1	11.10	8.47	9.79	112.2^{+}	15.74	11.07	13.41	116.9^{++}
	2	10.36	7.95	9.16	105.0	13.94	11.06	12.50	108.9
	3	10.12	8.23	9.17	105.2	13.09	11.52	13.31	107.2
	4	10.88	8.34	9.61	110.2	16.24	12.13	14.18	123.6^{+++}
	5	9.74	8.06	8.90	102.1	12.53	12.23	12.38	107.9
	6	9.15	8.33	8.73	100.1	13.81	11.60	12.70	110.7
Interaction A×C		10.23	8.22	***Factor*** A - 9.23		14.22	11.60	***Factor*** A – 12.91	
Nelina	1	10.58	7.07	8.82	101.2	14.36	9.92	12.14	105.8
	2	11.07	6.79	8.93	102.4	14.67	10.50	12.58	109.7
	3	10.17	6.50	8.34	95.6	14.35	10.15	12.25	106.8
	4	10.27	6.59	8.43	96.7	16.60	10.31	13.46	117.3^{++}
	5	10.82	6.52	8.67	99.4	15.09	10.03	12.56	109.5
	6	10.11	6.22	8.17	93.7	13.66	9.30	11.48	100.0
Interaction A×C		10.50	6.16	***Factor*** A - 8.56		15.00	10.04	***Factor*** A - 12.41	
				Factor B				***Factor*** B	
Interaction B×C	1	10.09	8.52	9.30	115.3^{+++}	14.00	10.84	12.42	106.8^{+}
	2	9.78	7.97	8.88	110.1^{+++}	14.00	10.74	12.37	106.4^{+}
	3	9.52	8.25	8.88	110.2^{+++}	13.10	11.38	12.24	105.3^{+}
	4	10.14	8.32	9.23	114.4^{+++}	15.33	11.98	13.66	117.5^{+++}
	5	9.54	8.25	8.90	110.3^{+++}	13.53	11.27	12.40	106.0^{+}
	6	8.62	8.51	8.06	**100.0**	12.49	10.76	11.63	**100.0**
Mean *factor* C		9.60	8.15			13.74	11.16		

Length of sprout

Errors at:	Factors: A	B	C	A × B	A × C	B × C	A × B ×C
P=5.0 %	0.406	0.445	0.257	0.996	0.575	0.630	1.409
P=1%	0.537	0.589	0.340	1.317	0.760	0.832	1.863
P=0.1 %	0.693	0.759	0.438	1.697	0.980	1.074	2.401

General mean: 8.959; Coefficient of variation: 9.72; Accuracy indicator: 5.61

Length of root

Errors at:	Factors: A	B	C	A × B	A × C	B × C	A × B ×C
P=5.0 %	0.647	0.647	0.373	1.585	0.915	0.915	2.241
P=1%	0.854	0.855	0.493	2.093	1.208	1.208	2.961
P=0.1 %	1.100	1.100	0.635	2.695	1.556	1.555	3.810

General mean: 12.48; Coefficient of variation: 11.39; Accuracy indicator: 6.57

to both storage periods and positive effect after the one-year storage was reported for the treatments 1, 3, 4 and 5 - 3.5-15.3% and after the two-year storage for options 2, 3, 4 and 5 - 6.6-16.0%. The strongest stimulating effect of the treatments was found for the Helius variety after the one-year storage of seeds - 34.8-43.9% at treatment variants 1, 2 and 4. The best variant of treatment was option 4, which option could be applied to all varieties for both storage periods. For the Chirpan-539 and Trakia varieties in case of two-year storage of seeds treatment option 3 could be used.

CONCLUSIONS

Electromagnetic treatment had stimulating effect on the studied sowing qualities of seeds. All treatment options had positive effect on the length of sprout and length of root. Treatment options 1 [U=(8…5)kV, τ =(15…35)s] and 4 [U=(6…3)kV, τ =(5…25)s] proved to be the best for the sprout length, for the root length and the total sprout and root length, the treatment option 4 was found to be the best.

Seeds stored for two years had 13-21% shorter length of the sprout and root than seeds stored for one year.

Greater total sprout and root length of than the control variant Chirpan-539 variety, untreated seeds, one-year storage, was accounted for the seeds stored for one year of the varieties: Natalia, treatment options 1 [U=(8…5)kV, τ =(15…35)s] and 4[U=(6…3) kV, τ =(5…25)s] – 22.9-24.1%; Nelina and Helius, treatment options 2 [U=(6…3)kV, τ =(15…35)s] and 4 [U=(6…3)kV, τ =(5…25)s] - 17.8-23.0% and 16.5-19.5%, respectively.

The strongest stimulating effect of the pre-sowing electromagnetic treatments on the total sprout and root length was found for the Helius variety, one-year storage of seeds and treatment variant 2 [U=(6…3)kV, τ =(15…35)s] (43.9% to the corresponding of this variety control).

REFERENCES

Aladjadjiyan, A., & Ylieva, T. (2003). Influence of stationary magnetic field on the early stages of the development of tobacco seeds (*Nicotiana tabacum* L.). *Journal of Central European Agriculture 4*(2), 131-138. https://jcea.agr.hr/en/issues/article/124

Aladjadjiyan, A. (2002). Study of the influence of magnetic field on some biological characters of Zea mais. *J Cent Eur Agric 3*(2), 89-94. https://jcea.agr.hr/en/issues/article/57

Alexander, M. P., & Doijode, S. (1995). Electromagnetic field, a novel tool to increase germination and seedling vigour of conserved onion (*Allium cepa* L.) and rice (*Oryza sativa* L.) seeds with low viability. *Plant Genet Resour Newslett, 1995; 104,* pp. 1-5.

Bilalis, D., Katsenios, N., Efthimiadou, A., & Karkanis, A. (2012). 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*(2), 143-150.

Bozhkova, Yu., Palov, Iv., & Stefanov, St. (1993). Influence of the pre-sowing electromagnetic treatment on the properties of cotton seeds. Agricultural engineering, XXX, No. 8, pp. 3-7.

Florez, M., Carbonell, M. V., & Martinez, E. (2004). Early sprouting and first stages of growth of rice seeds exposed to a magnetic field. *Electromagnetobiol. Med. 23*(2), 167–176. https://doi.org/10.3109/15368378.2011.624660

Leelapriya, T., Dhilip, K. S., & Sanker Narayan, P. V. (2003). Effect of weak sinusoidal magnetic filed on germination and yield of cotton (Gossypium spp.), Electromagn Biol Med, 22 (2-3), pp. 117-125, https://www.emf-portal.org/en/article/10676

Palov, Iv., Stefanov, St., Sirakov, K., Bozhkova, Yu., & Valkova, N. (1994). Possibilities of the pre-sowing electromagnetic treatments of cotton seeds. *Agricultural engineering*, XXXI, No. 6-7, 3-6.

Palov, Iv., Stefanov, St., Ganev, Hr., Zlatev, Zl., & 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.

Sastry, D. V. S. S. R., Upadhyaya, H. D., & Gowda, C. L. L. (2008). Seed viability of active collections in ex-situ genebanks: an analysis of sorghum germplasm conserved at ICRISAT genebank. *Journal of SAT Agricultural Research* 6, pp. 1-8.

Terziev, P., Palov, Iv., Stefanov, St., & Radev, R. (1995). Patent Holders. Device for pre-sowing electrical treatment of seed material. Patent for Invention of the Republic of Bulgaria, No. 30631, A 01 C 1/00

Vashisth, A., & Nagarajan, S. (2008). Exposure of seeds to static magnetic field enhances germination and early growth characteristics in chickpea (*Cicer arietinum* L.). *Bioelectromagnetics*, 2008, Oct., 29(7):571-8. doi: 10.1002/bem.20426. PMID: 18512697.

Vashisth, A., & Nagarajan, S. (2010). Effect on germination and early growth characteristics in sunflower (*Helianthus annuus*) seeds exposed to static magnetic field. *Journal of Plant Physiology*, Volume 167, Issue 2, 2010, Pages 149-156, ISSN 0176-1617, https://doi.org/10.1016/j.jplph.2009.08.011.