Influence of duration of storage and pre-sowing electromagnetic treatment on the sowing qualities of cotton seeds III. Sprout and root mass

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Abstract
The aim of this research was to study the influence of duration of storage and pre-sowing electromagnetic treatment on the development of primary root system of seeds of five Bulgarian cotton varieties - Chirpan-539, Trakia, Helius, Natalia and Nelina, stored before their treatment for one and two years. The seeds of each variety were treated in five electromagnetic fields, with different intensity and duration of exposure. It was found that the selected values of controllable factors had stimulating effect on the mass of sprout (8,9-13,8%) and mass of root (3,5-11,3%). The total sprout and root mass increased by 7.8 - 12.7% and the best treatment options were 1 [U =(8…5)kV, τ =(15…35)s] and 4 [U=(6…3) kV, τ =(5… 25)s]. Electromagnetic treatments had stronger positive effect on the total mass of sprout and root of seeds stored for one year, the increase was of 10.8-16.5%, and less for the seeds stored for two years (1.8 - 3.9%). Compared to the control variant Chirpan-539, untreated seeds stored for one year, higher sprout mass was accounted for the same variety, treatment option 5 [U =(4…2) kV, τ =(5…25) s]. Higher mass of root and total mass of sprout and root was reported for Nelina variety, treatment options 1 [U =(8…5)kV, τ =(15…35)s] and 2 [U =(6…3)kV, τ =(15…35)s].The strongest stimulating effect of treatments on studied characteristics was observed for the Helius variety. As for seeds stored for one year, best treatment option was 1 [U =(8…5)kV, τ =(15…35)s], the increase in sprout mass was by 36.0-57.1%, in root mass was by 0.9 -24.8%, the total mass of sprout and root increased by 27.1-48.5% compared to the variety corresponding control (untreated seeds, one-year storage). In the case of seeds stored for two years, the increase in the total mass of sprout and root was by 6.5-23.0%, and the best treatment option was 4 [U =(6…3)kV, τ =(5…25)s].

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

INTRODUCTION

Seed quality is of great importance for the development of crop production, human food and food security, especially in recent years, characterized by changing climatic conditions. A component of the quality of the seeds of agricultural crops is the characteristic of their viability. Obtaining high yields of quality products is determined by the ability of seeds to germinate, plants to grow together, evenly and stably under different environmental conditions (Savage & Bassel, 2016). Improving the initial development of seeds is the main goal of all seed producers. In recent years, in-depth research has been conducted on this issue.

Along with the traditional application of fertilizers and pesticides, various physical, biochemical, biophysical methods are used, including magnetic induction, laser radiation, electromagnetic waves (Moon & Chung, 2000; Galland & Pazur, 2005; Hernández et al., 2006; Aladjadjiyan, 2007; Aguilar et al., 2009; Domínguez et al., 2010). The effects of pre-sowing treatments of seeds with electromagnetic fields have been intensively studied due to their potential as innovative technologies that can be applied in the conditions of organic farming (Đukić et al., 2017; Ivankov et al., 2021).

Electromagnetic fields have been found to increase germination and improve the early growth characteristics of cotton (Bilalis et al., 2012). The treatment of cotton seeds before sowing in electromagnetic field has led to almost twice higher yields compared to untreated control seeds (Leelapriya et al., 2003). A number of scientists have reported an increase in germination, length and fresh weight of onion sprouts and roots (Alexander & Doijode, 1995), corn (Aladjadjiyan, 2002, 2010), rice (Florez et al., 2004), chickpeas (Vashisth & Nagarajan, 2008).

The aim of the present study was to establish the effect of pre-sowing electromagnetic treatment on the fresh mass of root and sprout of cotton seeds stored 1 and 2 years 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 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 the 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 the electromagnetic treatment, the cotton seeds stayed for 23 days. According to Palov et al. (1994) this stay, after treatment until sowing, was necessary so that the changes should occur in the seeds, which will subsequently favor the development of the plants.

Part of the seeds of each variety were not treated and served for control, to compare and report the effect of electromagnetic treatment.

After 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 up 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.

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 (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)					

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 – Durationof storage of seeds before their 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 corresponding to each variety controls.

RESULTS AND DISCUSSION

The results of the three-factor dispersion analysis of sprout mass showed significance of the three main factors and the interactions varieties × treatments and varieties × duration of storage (Table 2).The varieties interaction with storage periods had the strongest influence -29.38% on the sprout mass. Of the three main factors, the varieties had the most significant share- 18.40%. Electromagnetic treatments were significant, but had the lowest share- 4.51%. The storage periods and interaction of varieties × treatments had slightly greater and relatively equal weight of influence.

The root mass was influenced to the greatest extent by the interaction of the factors varieties × treatments - 18.67%. Of the significant interactions, treatments × duration of storage interaction was with the least force of influence. The other two interactions had greater and relatively equal share. Of the three main factors, the varieties had the greatest weight - 14.32%. The electromagnetic treatments influence was significant, but it had the smallest force of impact - 4.69%.

Varieties × duration of storage interaction had the strongest influence on the total mass of the sprout and root. The three main factors influence was statistically significant, as the varieties (13.65%) had the strongest impact and the electromagnetic treatments (4.95%) showed weakest.

Independent action of main factors on the mass of sprout, of root and total mass of sprout and root

Results for the independent action of the three main factors on the studied seed properties are presented in Fig. 1. Of the varieties, as an independent factor, the Chirpan-539 variety was distinguished by the largest mass of the sprout, while the largest mass of the root was found the Trakia variety, followed by the Nelina variety. Both varieties accumulated more mass of the root than the standard variety Chirpan-539, respectively by 13.4% and 5.0%. All varieties, as a separate factor, formed significantly

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

Factors	Degreeoffreedom	Mass of sprout			Mass of root			Total mass of sprout and root		
		Sum of squares	Sum of squares, (%)	Dispersion	Sum of squares	Sum of squares, (%)	Dispersion	Sum of squares	Sum of squares, (%)	Dispersion
A	4	0.1302	18.40	22.67^{+++}	0.0085	14.32	17.0^{+++}	0.1289	13.65	0.03^{+++}
B	5	0.0307	4.51	4.44^{++}	0.0028	4.69	4.45^{++}	0.0468	4.95	0.009^{+++}
C	1	0.0531	7.50	37.00^{+++}	0.0062	10.39	49.4^{+++}	0.0964	10.21	0.096^{+++}
A×B	20	0.0626	8.82	2.17^{++}	0.0110	**18.67**	4.44^{+++}	0.0979	10.36	0.0049^{++}
A×C	4	0.2078	**29.38**	36.5^{+++}	0.0059	10.10	12.0^{+++}	0.2640	**27.95**	0.065^{+++}
B×C	5	0.0117	1.65	1.63ns	0.0029	4.95	4.71^{+++}	0.0208	2.21	0.0041
A×B×C	20	0.0386	5.46	1.34ns	0.0068	11.44	2.72^{+++}	0.0605	6.41	0.0030
Errors	118	0.169	23.95		0.0147	24.82		0.2282	24.16	0.0019

lower total mass of the sprout and root compared to the untreated control of the Chirpan-539 variety with one year storage (Fig. 1 a).

All variants of pre-sowing electromagnetic treatment had significant stimulating effect on the mass of sprout, at option 1 [U = (8…5)kV, τ =(15…35)s] the increase was by 13.8%. The total mass of sprout and root for all variants of electromagnetic treatment was more by 7.8-12.7% compared to the control variant. A positive effect on the root mass was observed at treatment variant 4 [U = (6…3)kV and τ = (5…25)s], in which 11.3% more mass was formed than the untreated control (Fig. 1b).

The longer two-year storage period as a separate factor determined significantly less mass of the sprout by 8.5%, of root by 10.1%, and of total mass of sprout and root - by 8.9%, compared to the shorter one-year period (Fig. 1c).

Influence of the factors interactions on the sprout mass

As a result of the varieties × treatments interaction, largest mass of the sprout was found for the Chirpan-539 variety at treatment variants 1 and 5 - 11.7-12.4% above the control for the experiment (Table 3). Compared to the control for each variety, the pre-sowing electromagnetic treatment had the strongest positive effect on the seeds of the Helius variety. Sprout mass was increased at all treatment variants, from 19.5% to 34.7%. For the Trakia variety, treatment variant 5 and for Nelina variety, variant 2, the sprout mass increased by 14.6%.

As a result of the interaction of varieties × duration of storage, all varieties, with the exception of Chirpan-539 in two-year storage and Natalia in one-year storage, had less mass of the sprout at both storage periods, compared to the untreated variant of Chirpan-539 and one-year storage. The varieties reacted differently to the two storage periods. Chirpan-539, Trakia and Helius varieties had the same sprout mass in the two storage periods, while Natalia and Nelinavarieties had significantly less sprout mass in their two-year storage compared to the one-year storage period.

The interaction of treatments × duration of storage determined higher mass of sprout than the control (Chirpan-539, without treatment and one year storage) after the one-year storage of seeds,all treating options has positive effect. Sprout mass increased by 11.4 to 16.8% at option 1.

As a result of the three main factors interaction, varieties × treatments ×duration of storage, sprout mass was largest for the Chirpan-539 variety in one-year seed storage and treatment variant 5, exceeding the control variant by 11.0%. Compared to the corresponding control for the variety, it was found that the pre-sowing electromagnetic treatment had the strongest positive effect on the seeds of Helius variety. In their one-year storage the sprout mass increased by 36.0% to 57.1% at variant 1, and in two-year storage - by 8.3 to 23.3%, and the variants 4, 1 and 3 were best. For the variety Natalia pre-sowing electromagnetic treatment has a positive effect only for one-year storage of seeds. In all other varieties pre-sowing electromagnetic

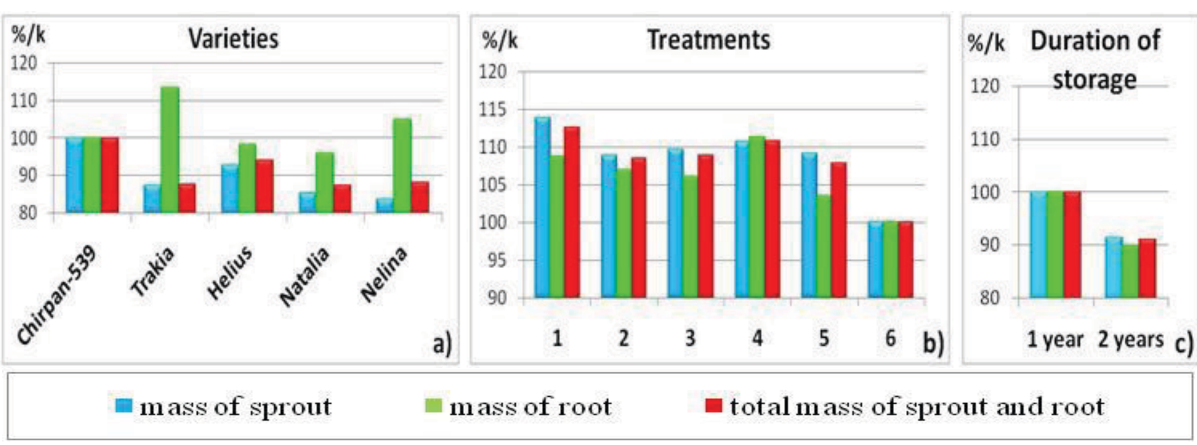

Figure 1. Independent action of the main factors – varieties (a), pre-sowing electromagnetic treatments (b) and duration of storage (c) on the mass of sprout, mass of root and total mass of sprout and root

treatment had positive effect in both periods of storage, for some varieties stronger in the second period of storage of seeds.

Influence of the factor interactions on the root mass

Variety Trakia, at treatment variants 2 and 4 and variety Nelina, at variants 1 and 2, formed largest mass of the root, exceeding by 21.7-23.5% the control variant - Chirpan-539, without treating, with one year seed storage (Table 3). Variety Nelina, at treatment variants 1, 2 and 3, showed the strongest increase in root mass - by 29.8% to 34.6% compared to its own control, variety Helius, at variant 5 - by 22.4%. Variety Trakia, with seeds storage periods of one year, had the largest root mass and was superior to the control variant by 16.1% - Chirpan-539 with one year of seed storage. Chirpan-539, Trakia and Nelina varieties, after their longer two-year storage, had a significantly less root mass than their one-year storage. Theother two varieties did not show differences in root mass after one- and two-year storage. Highest positive effect was found for the treatment options 1 and 4 with one-year storage of seeds. The root mass was increased by 16.1% compared to the control Chirpan-539 without treating and one year of storage. In the case of longer two-year storage, compared to the corresponding control, the seedspre-sowing electromagnetic treatment had the best stimulating effect at treatment variants 3 and 4, with an increase in root mass by 7.2% and 8.1%, respectively.

As a result of the three main factors interaction (varieties × treatments × duration of storage), largest root mass was formed at the variety Nelina, for the seeds stored for one year and treatment options 1, 2 and 3 - by 34.5-44.0% over the control variant. More root mass, in one-year storage of the seeds, was also accounted for the Trakia variety, at options 2 and 4, and for the Chirpan-539 variety, at variants 1 and 3. Root mass was respectively 31.0-31.9% and 21.5-25.9% more than the control variant.

Influence of the factor interactions on the total sprout and root mass

As a result of the varieties × treatmentsinteraction, the total sprout and root mass forthe Chirpan-539 variety at treatment variants 1 and 5 was more by 9.8-12.9% than the control variant, and for the Helius variety, at variant 1 it was more by 10.0%. Helius variety reacted most strongly to the pre-sowing electromagnetic treatment, compared to the cor-

Table 3. Influence of electromagnetic treatment on the mass of sprout and mass of root of seeds of 5 varieties of cotton after 1 and 2 years duration of storage

Varieties	Treatments	Mass of sprout, g				Mass of root, g			
		Duration of storage		Interaction A×B	In % to control	Duration of storage		Interaction A×B	In % to control
		1 year	2years			1 year	2 years		
Chirpan-539	1	0.484	0.487	0.486	111.7^{+}	0.128	0.107	0.118	102.6
	2	0.438	0.466	0.452	103.9	0.108	0.116	0.112	97.4
	3	0.454	0.477	0.466	107.1	0.112	0.124	0.118	102.6
	4	0.479	0.418	0.449	103.2	0.139	0.105	0.122	106.1
	5	0.493	0.484	0.489	112.4^{+}	0.142	0.123	0.132	114.8^{++}
	6	**0.444**	0.427	**0.435**	**100.0**	**0.116**	0.114	**0.115**	**100.0**
Interaction A × C		0.465	0.460	***Factor A – 0.463***		0.124	0.115	***FactorA*** – 0.119	
Trakia	1	0.405	0.407	0.406	93.3	0.146	0.122	0.134	116.5^{++}
	2	0.406	0.389	0.398	91.5	0.153	0.130	0.142	123.5^{+++}
	3	0.399	0.412	0.405	93.1	0.141	0.128	0.134	116.5^{++}
	4	0.399	0.424	0.411	94.5	0.152	0.128	0.140	121.7^{+++}
	5	0.419	0.445	0.432	99.3	0.134	0.123	0.128	111.3^{+}
	6	0.368	0.386	0.377	86.7^{00}	0.136	0.123	0.129	112.2^{+}
Interaction A × C		0.399	0.411	***Factor*** A – ***0.405***		0.144	0.126	***Factor*** A – 0.135	

Helius	1	0.484	0.470	0.477	109.7	0.131	0.125	0.128	111.3^{+}
	2	0.447	0.398	0.423	97.2	0.127	0.103	0.115	100.0
	3	0.420	0.448	0.434	99.8	0.106	0.117	0.112	97.4
	4	0.443	0.493	0.468	107.6	0.129	0.133	0.131	113.9^{+}
	5	0.419	0.433	0.426	97.9	0.113	0.107	0.110	95.7
	6	0.308	0.400	0.354	81.4^{000}	0.105	0.108	0.107	92.6
Interaction A × C		0.420	0.440	***Factor*** **A – *0.430***		0.119	0.115	***Factor*** A –0.117	
Natalia	1	0.418	0.373	0.396	91.0	0.110	0.103	0.106	92.1
	2	0.418	0.376	0.397	91.3	0.101	0.111	0.106	92.1
	3	0.456	0.361	0.409	94.0	0.111	0.113	0.112	97.4
	4	0.425	0.378	0.402	92.4	0.130	0.121	0.126	109.6
	5	0.414	0.347	0.380	87.3^{0}	0.120	0.113	0.117	101.7
	6	0.396	0.377	0.387	89.0^{0}	0.122	0.115	0.119	103.5
Interaction A × C		0.421	0.369	***Factor*** **A – *0.395***		0.116	0.113	***Factor*** A – 0.114	
Nelina	1	0.498	0.329	0.413	94.9	0.167	0.113	0.140	121.7^{+++}
	2	0.491	0.339	0.415	95.4	0.167	0.114	0.140	121.7^{+++}
	3	0.474	0.300	0.387	89.0^{0}	0.156	0.114	0.135	117.4^{++}
	4	0.440	0.338	0.389	89.4^{0}	0.133	0.114	0.123	106.9
	5	0.458	0.266	0.362	83.2^{00}	0.113	0.105	0.109	94.8
	6	0.443	0.281	0.362	83.2^{00}	0.110	0.097	0.104	90.4
Interaction A × C		0.467	0.309	***Factor*** **A – *0.388***		0.141	0.109	***Factor*** A – 0.125	
				Factor B				***Factor*** B	
InteractionB×C	1	0.458	0.413	0.436	113.8^{+++}	0.137	0.114	0.125	108.7^{+++}
	2	0.440	0.394	0.417	108.9^{+++}	0.131	0.115	0.123	106.9^{+++}
	3	0.441	0.399	0.420	109.7^{+++}	0.125	0.119	0.122	106.1^{++}
	4	0.437	0.410	0.424	110.7^{+++}	0.137	0.120	0.128	111.3^{+++}
	5	0.440	0.395	0.418	109.1^{+++}	0.124	0.114	0.119	103.5
	6	**0.392**	0.374	**0.383**	**100.0**	**0.118**	0.111	**0.115**	**100.0**
Mean factor C		0.435	0.398			0.129	0.116		

Errors at:	Mass of sprout						
	Factors						
	A	B	C	A × B	A × C	B × C	A × B ×C
P=5.0 %	0.018	0.019	0.011	0.043	0.025	0.027	0.061
P=1.0%	0.023	0.026	0.015	0.057	0.033	0.036	0.081
P=0.1%	0.030	0.033	0.019	0.074	0.043	0.047	0.104
General mean: 0.417; Coefficient of variation: 9.07; Accuracy indicator: 5.24							

Errors at:	Mass of root						
	Factors						
	A	B	C	A × B	A × C	B × C	A × B × C
P=5.0 %	0.005	0.006	0.003	0.013	0.007	0.008	0.018
P=1.0%	0.007	0.007	0.004	0.017	0.010	0.011	0.024
P=0.1%	0.009	0.010	0.006	0.022	0.013	0.014	0.031
General mean: 0.123; Coefficient of variation: 9.13; Accuracy indicator: 5.27							

responding control. The increase in the total mass of sprout and root was from 16.5% to 31.2% at treatment variant 1. The control variant Chirpan-539 variety and storage period of the seeds for one year had the largest total mass of sprout and root. All varieties had significantly lower total mass of sprout and root in the two-year storage of the seeds compared to their one-year storage, with the exception of the varieties Chirpan-539 and Trakia.

Pre-sowing electromagnetic treatment had significant positive effect only on seeds stored for one year, increasing the total mass of sprouts and roots by 10.8-16.5%. Processing option 1 was best.

Nelina variety had the highest total mass of sprouts and roots in one-year storage of seeds and treatment options 1 and 2 - by 17.5-18.7% above the standard variant – the variety Chirpan-539, without treatments and storage for one year (Fig. 2a). Higher indexes than the control variant were observed for Chirpan-539variety, one year storage and treatment variant 5 - 13.2%, for Nelina variety, one year storage and treatment variant 3 - 12.3%.

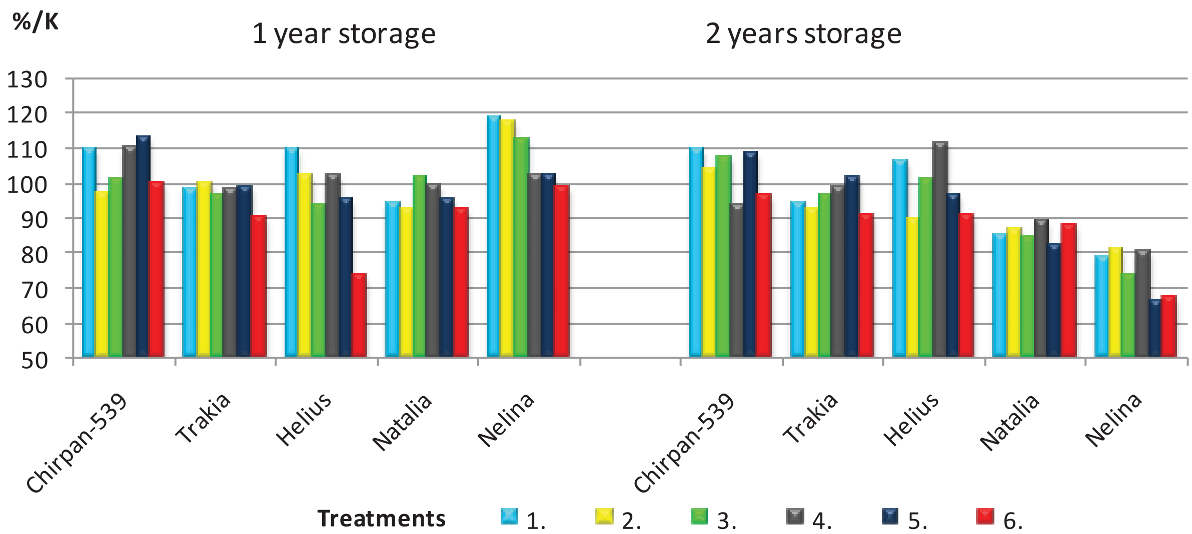

Figure 2a). Interaction of factors varieties × treatments ×duration of storage (A × B × C) on the total mass of sprout and root relative to the control (K) - variety Chirpan-539, one year duration of storage, without treatments

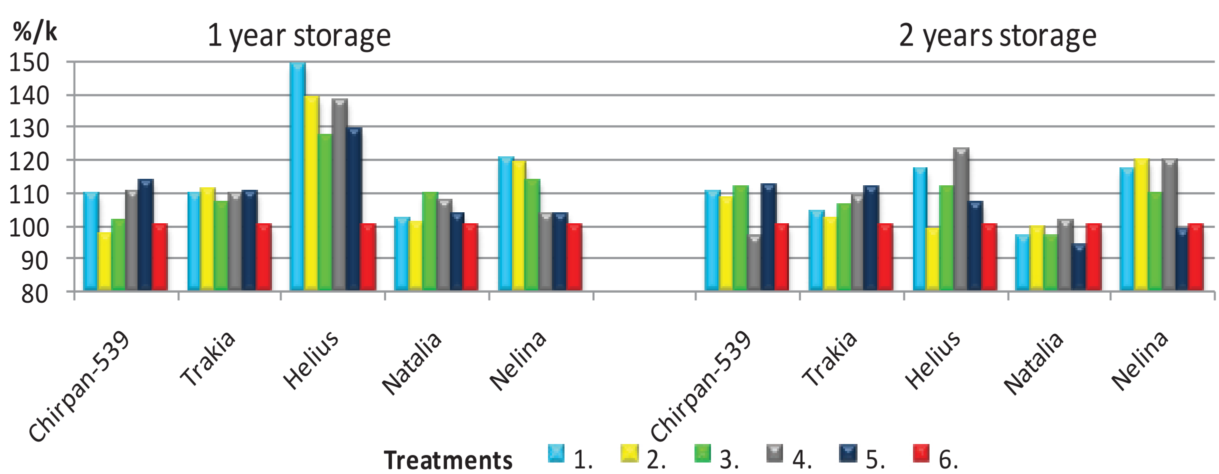

Figure 2b). Interaction of factors varieties × treatments ×duration of storage (A × B × C) on the total mass of sprout and root relative to the corresponding control for each variety (k)

To the control corresponding to each variety, Helius variety reacted most strongly to the electromagnetic treatment (Fig. 2b). For this variety, inone year storageof seed, all variants of electromagnetic treatments had positive effect and the total mass of sprouts and roots wasincreased from 27.1% to 48.5% at option 1, while in two-year storage option 4 - 23.0% was best. As for Chirpan-539 variety, for both storage periods, option 5 was best, the total mass of sprout and root was increased by 13.2% and 12.2%, respectively.

CONCLUSION

Pre-sowing electromagnetic treatments had stimulating effect on the mass of sprout (8.9-13.8%), mass of root (3.5-11.3%) and total mass of sprout and root (7.8-12.7%).The best processing options were 1 [U =(8…5)kV, τ =(15…35)s] and 4 [U =(6…3)kV, τ =(5…25) s].

Seedsstored for one year had better effect of electromagnetic treatments (10.8-16.5%) than seeds stored for two years (1.8 - 3.9%).

Compared to the control Chirpan-539, untreated seeds stored for one year, higher mass of sprout was found for the same variety, treatment option 5 [U =(4…2)kV, τ =(5…25)s], higher mass of root and total mass of sprout and root was found for the Nelina variety, treatment options 1 [U =(8…5)kV, τ =(15…35)s] and 2 [U =(6…3)kV, τ =(15…35)s].

Helius variety showed the strongest stimulating effect of treatments, for the seeds stored for one year,the increase in sprout mass was by 36.0-57.1%, in root mass was by 0.9 -24.8% and in total mass of sprout and root was by 27.1-48.5%, compared to the variety corresponding control (untreated seeds, one-year storage). Besttreatment option was 1 [U =(8…5) kV, τ =(15…35)s]. In the case of seeds stored for two years, the increase in total mass of sprout and root was by 6.5-23.0%, and the best treatment option was 4 [U =(6…3) kV, τ =(5…25)s].

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