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Effect of year conditions and pre-sowing electromagnetic treatment of triticale seeds on grain yields and yield parameters

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Abstract: Various methods, including physical ones are used to improve the seed quality. In order to determine the effect of electromagnetic influence on triticale grain yield and its parameters in two contrasting agro-meteorological years, a field experiment was conducted for the period 2017-2019. The experiment was carried out on Pellic Vertisols, a predecessor of sunflower. Phosphorus fertilizer was applied at 60 kg/ha in autumn with the main tillage. The crop was managed for pests, weeds, and diseases according to permitted pesticides and standard technology for growing cereals. Two factors were tested: variety and pre-sowing electromagnetic treatment (EMT) (E1 and E2). The seeds were treated with the following factor values: E1–U = 5.2 kV, τ = 24 s, T = 14 days; E2–U = 5.0 kV, τ = 50 s, T = 7 days. The results showed that the conditions of the year have a different effect on the grain yield and its parameters for the two varieties within 72.52%–88.22% for the Boomerang variety and 41.73%–96.16% for the Colorit variety. The effect of electromagnetic influence on grain yield is 8.83% for the Boomerang variety and 36.67% for the Colorit variety. An 8.1% increase in grain yield for the Boomerang variety was found for one of the years. The correlations are expressed in negative dependencies of grain yield with the number and mass of grains in the spike and positive of yield with the mass of thousand grains and height.

Key words: grain yields; electromagnetic treatment; triticale seeds

INTRODUCTION

Seeds are carriers of various qualities – physical, biochemical, physiological, genetic, etc. Many of these qualities are directly related to the yield of field crops, and the most important seed qualities are germination and germination energy.

A special place in the technology of growing field crops is occupied by pre-sowing seed treatment. It is known that in order to improve the sowing qualities of seeds, various methods are used, including physical ones. Electromagnetism, or the effect of artificial electromagnetic fields, has been widely studied on various fields and vegetable crops. One of these field crops is cotton. Pre-sowing treatment of seeds was carried out with electromagnetic fields with increased values of the voltage used at different treatment durations. In Koleva and Radevska (2020) it is shown that after such treatment, at certain values of the controllable factors, the sowing qualities of the seeds improve. In other studies, the seeds were left for one year after pre-sowing treatment. It was found that after this stay, the seeds retained the effect of the electromagnetic treatment - in-

creased their laboratory germination (Koleva and Radevska, 2021a) and the length of the sprouts and roots (Koleva and Radevska, 2021b). Many benefits have been reported in plants, given the determination of positive values of the levels of factors and the reveals of the molecular mechanisms of processes in the cell (Xia et al., 2024). Shibryaeva et al. (2024) showed that under the influence of a magnetic field, the permeability of cell membranes increases, which accelerates the diffusion of molecules and ions through the membrane of wheat and barley seeds, which leads to an increase or slowdown in the rate of chemical reactions depending on the water content in the plant cell. A study by Azharonok et al. (2009) showed that a low-intensity, high-frequency electromagnetic field can be used as a mediator of cell receptors of seeds, triggering intracellular mechanisms that lead to an improvement in their seeding qualities. Pre-sowing treatment of corn seeds under an electromagnetic field led to better performance in germination kinetics, biochemical analyses and growth dynamics, according to a study by Muhammad et al. (2024). A positive effect on the amount of wet gluten (Bezpal'ko et al., 2021) and an increase in germination after storage of wheat grain (Kovra et al., 2022) were also found. Ayesha et al. (2023) indicated that the effect of electromagnetic radiation (MWR) depends on the type, size and moisture content of the seeds, environmental factors, duration of treatment and field intensity. Exposure of seeds to electromagnetic fields increases the activity of α-amylase in the first three days after sowing, thus giving an advantage in germination, increasing fresh biomass in wheat (Poghosyan et al., 2023). These microprocesses mainly lead to "stimulation of coleorhiza and root germination and coleoptile growth" (Cecchetti et al., 2022) and hence faster initial development. For triticale, it has been observed that significant improvements of seedlings with seed treatment developed faster and more abundantly (Florez et al., 2014). In addition, there are studies that have found certain levels of electromagnetic fields that positively affect laboratory parameters and initial growth of triticale (Alvarez et al., 2012; Muhova et al., 2016; Florez et al., 2016; Sirakov et al., 2016; Sirakov et al., 2021), as well as an increase in wheat production under field conditions (Palov et al., 2016).

A small number of studies examine how genotype and environment interact with electromagnetic treatment, while the majority concentrate on evaluating laboratory indicators.

Given the current opinions on climate warming and reducing carbon emissions, according to the European Parliament's European Green Deal, the search for ecological approaches to increasing yield is a promising area (https://eur-lex.europa.eu/legal-content/BG/TXT/?qid=1576150542719&uri=COM:2019:640:FIN).

The aim of the study is to assess the effect of pre-sowing electromagnetic treatment on triticale grain yield and its parameters in two contrasting agro-meteorological years.

MATERIAL AND METHODS

During the period 2017-2019, a three-factor experiment was conducted on a conventional field using a block method in four replications on Pellic Vertisols. The experimental plot was 18 m² in size, and the seeding rate was 550 seeds per m². Sowing over the years was carried out later than the adopted optimal period for cereal crops in Central Southern Bulgaria. After harvesting the predecessor sunflower, the soil was discised twice. In the autumn before sowing, 60 kg/ha of phosphorus fertilizer was applied, and the soil was cultivated. The sowing of triticale was carried out on 9.11.17 and 30.11.18. During the growing season, the crop was controlled for pests, weeds, and diseases according to the permitted pesticides. Two factors were tested: variety (Boomerang and Colorit) and pre-sowing electromagnetic treatment (EMT) (E1 and E2). Option E0 is without electromagnetic influence. The limits of the electromagnetic influence factors were previously established with laboratory tests – voltage between the electrodes – U (kV), seed exposure time – τ (s), and time from treatment to sowing T (days), at which an increase in seed germination and seed germination energy of the two varieties

is expected, respectively, an expected increase in yield. In the present study, the seeds were treated with the following values of controllable factors:

-for option E1: U = 5.2 kV, τ = 24 s, T = 14 days;

-for option E2: U = 5.0 kV, τ = 50 s, T = 7 days.

Before harvest, 20 spikes (10 spikes from each plot), were collected to characterize the spike structure: spike length (SL), number of grains in spike (NGS), mass of grains in spike (MGS), and 1000-grain mass (TGM). The height of the crop was measured from the soil surface to the central ear without the awns. Harvest was carried out at full maturity of the crop. Data from the two harvest years (2018 and 2019) were analyzed with ANOVA (Penchev et al., 1989-1991). Pearson's simple linear correlation coefficients (r) were determined by Statistics 13.

RESULTS AND DISCUSSION

During the 2017–2018 growing season, 103.0 mm more precipitation was recorded, as the wettest months were October, February, March, and June, respectively, with 33.1, 70.6, 37.1, and 37.1 mm more (Figure 1). These humidification conditions improved the conditions for seedling emergence and spring sprouting. The average daily air temperatures in December 2017, January, April, and May 2018 exceeded the reference values by 2.2, 1.3, 4.0, and 1.7°C, respectively. The sum of the average daily temperatures of the months during the growing season is 2824.1°C, and compared to the reference period (2513.2°C), it is 310.9°C more.

In November 2018 and June 2019 of the second period, an abundance of precipitation was recorded, which exceeded the climatic average by 41.6 and 72.4 mm. The precipitation in November accelerated germination, but the lower amount in February and March did not provide the necessary moisture for good tillering. In May, precipitation was 35.9 mm less, and drier conditions led to poor pollination of flowers. The total precipitation value is 383.9, which is 54.7 mm lower than the value for multi-year data (438.6 mm). Regarding average daily air temperatures, February, March, and June were warmer by 1.4, 2.2, and 1.3°C, respectively. The sum of the average daily temperatures of the months during the growing season is 2692.2°C and, compared to the reference period (2513.2°C), is 179.0°C higher.

The results in Table 1 show that in 2019, the grain yield, number of grains per spike, mass of grains per spike, and mass of 1000 grains for Boomerang were significantly lower compared to the control year 2018, and the values were 79.1%, 82.3%, 69.4%, and 80.7%, respectively. An increase in the height value by 0.9% compared to the control has been ascertained, but it is not significant.

Compared to E0, the yield was significantly higher by 8.6% for E1 (2937.9 kg/ha). An increase

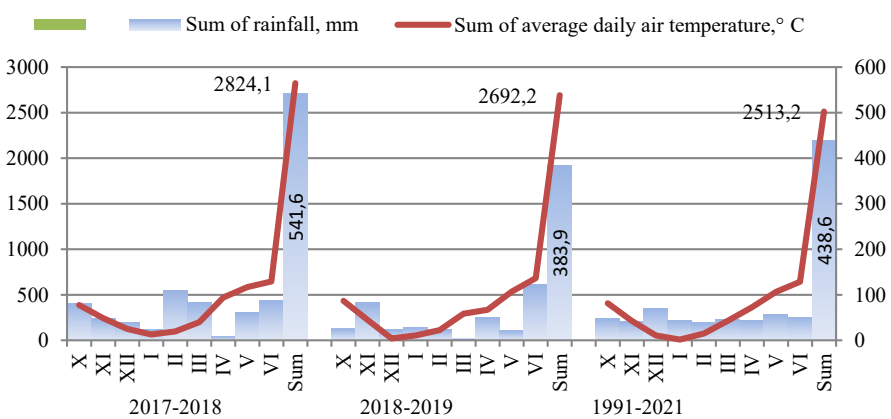


Figure 1. Meteorological conditions during triticale vegetation

Table 1. Grain yield and parameters of grain yields for Boomerang variety

Factors		Grain yield (kg/ha)	Plant height (cm)	Number of grain in spike	Mass of grain in spike (g)	Length spike (cm)	Thousand grains mass (g)
Year							
2018 (Control)		*3100.2*	*106.0*	*60.9*	*2.97*	*10.9*	*50.32*
2019		2482.3 ^{000}	106.9 ^{ns}	50.1^{000}	2.16 ^{000}	10.7 ^{ns}	40.6 ^{000}
LSD test %	5.0	16.9	2.5	3.2	0.1	0.6	2.2
	1.0	23.4	3.9	5.1	0.2	1.0	3.4
	0.1	32.4	6.6	8.7	0.4	1.7	5.8
EMT							
E0 (Control)		*2705,2*	*108.0*	*54.6*	*2.58*	*11.1*	*45.71*
E1		2937.9***	106.1 ^{ns}	55.4 ^{ns}	2.48 ^{ns}	10.8 ^{ns}	43.60 ^{ns}
E2		2696.2 ^{ns}	105.4 ^{ns}	56.5 ^{ns}	2.64 ^{ns}	10.4 ^{ns}	47.10 ^{ns}
LSD test %	5.0	20.8	3.0	4.0	0.2	0.8	2.7
	1.0	28.7	4.8	6.2	0.3	1.2	4.2
	0.1	39.7	8.1	10.6	0.4	2.1	7.1
Y × EMT							
2018							
E0 (Control)		*3052,1*	*110.0*	*60.3*	*3.01*	*11.1*	*49.90*
E1		3300.7***	105.6^{0}	59.5 ^{ns}	2.77 ^{0}	10.9 ^{ns}	46.39 ^{ns}
E2		2947.9^{000}	102.6^{0}	63.0 ^{ns}	3.13 ^{ns}	10.7 ^{ns}	54.68 *
2019							
E0		2358.3 ^{000}	106.1 ^{ns}	48.8^{00}	2.15 ^{000}	11.1	41.52 ^{00}
E1		2643.5 ^{000}	106.6 ^{ns}	51.4^{00}	2.2 ^{000}	10.8 ^{ns}	40.80 ^{00}
E2		2444.5 ^{000}	108.2 ^{ns}	50.1^{00}	2.14 ^{000}	10.1 ^{ns}	39.51 ^{00}
LSD test %	5.0	29.3	4.3	5.6	0.2	1.1	3.8
	1.0	40.6	6.7	8.8	0.4	1.7	5.9
	0.1	56.1	11.5	15.0	0.6	2.9	10.1
Effect of factors (η %)							
Source of variation	Options	83.05***	81.14 ^{ns}	93.18**	92.64***	53.49 ^{ns}	97.01 **
	Year (Y)	72.52***	3.03 ^{ns}	88.22***	86.33 ***	5.47 ^{ns}	77.02***
	EMT	8.83*	19.46 ^{ns}	1.92 ^{ns}	2.12 ^{ns}	41.32 ^{ns}	6.76 ^{ns}
	Y×EMT	1.70 ^{ns}	58.65*	3.05 ^{ns}	4.21 ^{ns}	6.69 ^{ns}	13.22 *
	Error	16.7	18.3	5.96	1.83	34.81	2.92

* , ** , *** *significant at p<1.0%, p<0.1% and p>0.1%;* ^{0} , ^{00}, ^{000} *significant at p< 0.05, 0.01, 0.001;* ^{ns} *not significant.*

in the number of grains per spike for E1 and E2 was reported by 1.5% and 3.3%, respectively, but not significant. For the E2 option, higher values are also observed, but there is no statistical confirmation for the mass of grains in a spike by 2.3% and the mass of 1000 grains by 3.4%. These results are in harmony with other studies with cereal crops. It has been found that the use of a pulsed electromagnetic field for pre-sowing treatment improved the germination of durum wheat, tillering, dry weight, leaf area, chlorophyll content, photosynthesis rate, transpiration rate, stomatal conductance and yield (Katsenios et al., 2016). Other authors found an increase in the yields of spring barley and winter triticale from 4.9 to 8.4 kg/da as a result of an increase in productive tillering, which is accompanied by the accumulation of biomass and, as a consequence, the formation of larger grains and higher yield per spike (Yudaev et al., 2024).

The influence of the interaction of the two factors A×B showed that in 2018, the E1 option recorded an 8.1% higher yield (3300.7 kg/ha). The difference is significant at p = 0.1%. The values of the other traits are lower to control. Compared to E0, PH (96.0%) and MGS (92.0%) are significant at p < 0.05. The NGS, MGS and TGM for E2 mark a slight increase of 4.4, 4.0 and 9.6%, respectively, and the value of TGM for the E2 option is significant at p = 5.0%.

For the conditions of 2019, grain production for E1 also showed a higher value (2643.5 kg/ha) compared to E0 and E2 but lower than the control (3052.1 kg/ha). Similarly, NGS (51.4) and MGS (2.2 g) for E1 exceed the values of the other two options, E0 and E2. A greater PH value for E2 (108.2 cm) is obtained. The mentioned values for E1 and E2 options are significant at p < 0.01% and p < 0.001% compared to E0. In general, a trend towards lower average values of the indicators in 2019 of GY (2482.1 kg/ha), NGS (50.1), MGS (2.16 g), LS (10.7 cm) and TGM (40.61 g) is highlighted.

A high effect of the conditions of the year on grain yield (72.52%), NGS (88.22%), MGS (86.33%), and TGM (77.02%) was found. For triticale, the influence of the conditions of the year on the yield was confirmed (Kyrylchuk et al., 2023). It is established that the mentioned average values of the yield and its parameters are lower in 2019, as indicated above. EMO shows a lower than typical effect on grain yield (η=8.83%). These results correlate with the significant values above by the LSD test, obtained for the conditions of the year and EMO. The influence of the interaction of EMO × year is high for PH (η=58.65%) and for TGM (η=13.22%) is characteristic. These established effects may be the result of the lower significant PH values in 2018 for options E1 and E2 (105.6 and 102.6 cm) in contrast to 2019. The time of sowing is also important for good crop development when the conditions are suitable for the formation of a good root system, leaf mass, and hence optimal photosynthetic surface. Similarly, for the indicator TGM, a higher value for option E2, reported for the conditions of 2018 is confirmed.

According to Table 2, the influence of the conditions of the year showed that all indicators for the Colorit variety, except PH, are significantly lower in 2019. This is in accordance with the influence of year (η = 41.73%).

Regarding the indicators for the E1 and E2 options, no significant increase in the values of the yield parameters compared to E0 is noted, as follows: NGS (0.6 and 2.7%), MGS (3.8 and 4.6%), and TGM (3.1 and 2.5%), respectively, in brackets for options E1 and E2. The grain yield for both options of EMO is lower to control, 90.4% and 87.7%, respectively. The effect of EMO is 36.67% and approaches the effect of the year (41.73%), unlike the established effects for the variety Boomerang, where an increase in the effect of the year (72.52%) and a decrease in the effect of EMO (8.36%) are observed. It is possible that the selected levels of the EMO factors had a suppressive effect during the initial period of plant development of the Colorit variety.

The influence of the interaction of the conditions of the year and EMO showed that in 2018, an increase in values for the E1 option was recorded for NGS and MGS by 2.7% and 13.4%, respectively, and for MGS it was significantly higher by 7.6%. For option E2, PH, NGS, and LS are significantly higher, to control by 3.01%, 12.0%, and 0.9%, respectively. Statistically confirmed higher are the values for NGS and TGM – 7.2 and 6.9%, respectively.

In 2019, the values of the indicators for the E1 and E2 options are lower than the control option for the indicators GY, NGS, MGS, and TGM. The highest values are for option E0.

The established effects of the factors for the Colorit variety determine a dominant influence of the conditions of the year for NGS (89.78%), MGS (83.79%), LS (52.23%), and TGM (96.19%). The listed indicators mainly participate in the formation of the production of grain plants and are strongly influenced by the conditions of the year, as established by other studies for durum wheat and barley (Dimova et al., 2014; Taneva and Dragov, 2024; Petrova and Stoyanov, 2024).

It should be noted that the selected levels of the electromagnetic influence factors have a dif-

ferent effect on the yield of the two varieties. Our previous studies also showed similar results regarding laboratory indicators of triticale varieties used in this study (Sirakov et al., 2016; Sirakov et al., 2019).

The relationships between GY and yield-forming parameters, based on different conditions of the years and EMO (E1 and E2 options), illustrate different dependencies (Table 3).

In 2018, GY was negatively related to NGS and MGS. There are studies that demonstrate similar results. A negative and significant correlation given different conditions of the year was observed between yield in wheat with height (r = -0.916 and r = -0.891). In contrast to our study, a negative relationship of height with the mass of grains in a spike (r = -0.922) and the number of grains in a spike (r = -0.664) confirmed our results (Rind et al., 2023). Other authors also found negative correlations between grain yield and the number of grains in a spike (-0.230) and mass of 1000 grains (-0.280) (Philipp et al., 2018).

In 2019, GY showed a positive and confirmed relationship with PH (0.886) and TGM (0.951)

Table 2. Grain yield and parameters of grain yields for Colorit variety

Factors		Grain yield (kg/ha)	Plant height (cm)	Number of grain in spike	Mass of grain in spike (g)	Length spike (cm)	Thousand grains mass (g)
Year							
2018 (Control)		*2473.4*	*101.4*	*67.9*	*3.27*	*11.2*	*48.05*
2019		2088.7^{000}	95.2^{ns}	56.9^{000}	2.14^{000}	10.1^{0}	33.29^{000}
LSD test %	5.0	12.2	7.2	2.0	0.3	0.9	1.7
	1.0	16.8	11.3	3.2	0.4	1.5	2.7
	0.1	23.2	19.3	5.4	0.7	2.5	4.6
EMT							
E0 (Control)		*2523.6*	*100.8*	*62.0*	*2.63*	*10.8*	*39.92*
E1		2227.8^{000}	97.5^{ns}	62.4^{ns}	2.73^{ns}	10.4^{ns}	41.17^{ns}
E2		2091.7^{000}	96.8^{ns}	63.7^{ns}	2.75^{ns}	10.8	40.93^{ns}
LSD-test %	5.0	14.9	8.8	2.5	0.3	1.2	2.1
	1.0	20.6	13.9	3.9	0.5	1.8	3.3
	0.1	28.4	23.6	6.6	0.9	3.1	5.7
Y×EMT							
2018							
E0 (Control)		*2668.1*	*100.8*	*65.7*	*3.01*	*11.2*	*45.83*
E1		2412.5^{000}	99.8^{ns}	67.5^{ns}	3.42^{ns}	11.2	49.32*
E2		2339.6^{000}	103.8^{ns}	70.4*****	3.37^{ns}	11.3^{ns}	49.01*
2019							
E0		2379.2^{000}	100.8	58.4^{00}	2.25^{00}	10.5^{ns}	34.01^{000}
E1		2043.1^{000}	95.2^{ns}	55.4^{000}	2.04^{00}	9.5^{0}	33.02^{000}
E2		1843.8^{000}	89.8^{ns}	56.9^{00}	2.14^{00}	10.4^{ns}	32.85^{000}
LSD test %	5.0	21.1	12.5	3.5	0.5	1.6	3.0
	1.0	29.1	19.6	5.5	0.7	2.6	4.7
	0.1	40.2	33.4	9.3	1.3	4.4	8.0
Effect of factors (η %)							
Source of variation	Options	80.44***	64.10^{ns}	97.61**	92.99**	68.06^{ns}	98.61***
	Year(Y)	41.73***	29.21^{ns}	89.78**	87.39***	52.23*	96.19***
	EMT	36.67**	9.09^{ns}	2.68^{ns}	0.76^{ns}	7.77^{ns}	0.52^{ns}
	Y×EMT	2.05^{ns}	25.79^{ns}	5.16^{ns}	4.8 3^{ns}	8.06^{ns}	1.91^{ns}
	Error	13.75	29.94	2.28	3.86	28.87	1.00

* ,** , *** *significant at p<1.0%, p<0.1% and p>0.1%;* ^{0} , ^{00}, ^{000} *significant at p< 0.05, 0.01, 0.001;* ^{ns} *not significant.*

Table 3. Pearson′s correlation coefficients between grain yield and yield parameters by years

2018						
Traits	GY	PH	LS	NGS	MGS	TGM
GY	1					
PH	0.610	1				
LS	-0.317	-0.152	1			
NGS	-0.862***	-0.407	0.630	1		
MGS	-0.930***	-0.734**	0.089	0.730**	1	
TGM	-0.030	-0.383	-0.231	0.093	0.258	1
2019						
GY	1					
PH	0.886***	1				
LS	0.405	0.508	1			
NGS	-0.848***	-0.734**	-0.029	1		
MGS	0.219	0.409	0.736**	-0.033	1	
TGM	0.951***	0.831***	0.439	-0.881***	0.278	1

*GY-grain yield; PH-plant height; LS-length of spike; NGS-number of grains in spike; MGS-mass of grains in spike; TGM-mass of 1000 grains; ** significant at p<0.01; *** significant at p<0.001.*

and a negative one with NGS (-0.848). PH and TGM are positively related to GY in triticale varieties – 0.880 and 0.836, respectively - and have a direct positive effect on yield, according to a study by Neykov (2024). Kizilgeçi (2019) also demonstrated a positive correlation of TGM with GY in triticale (0.707). Rajičić et al. (2020) found a positive relationship of yield with TGM for two seasons (0.648 and 0.493) and, in one year, a negative one (-0.392).

CONCLUSIONS

The production and parameters of production height, spike length, number of grains in spike, mass of grains in spike, and mass of thousand grains of two triticale varieties, were evaluated against the background of two options of presowing electromagnetic seed treatment. According to the conducted analyses, it can be concluded that the factors of the year's conditions and the electromagnetic treatment have a different effect on the two varieties, and their combined effect is manifested in the height and mass of a thousand grains for the Boomerang variety. The effect of the year's conditions is dominant and very high for the Boomerang variety, and for the Colorit variety, it is greater than the typical one and similar to the effect of electromagnetic treatment. An increase of 8.1% in grain yield for the E1 option for the Boomerang variety in one of the years was found, as a result of a low effect of electromagnetic treatment. Various positive and negative correlations of grain yield with yield parameters in both years were established.

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