Change in the growth parameters of soft wheat *Triticum aestivum* (L.) after pretreatment of seeds with a pulsed magnetic field

N.A. Rodenko[1,2,*], *O.V.* Blednykh[1], *V. A.* Glushchenkov[1,2], *Yu. V.* Degteva[1,2]

[1]Samara Federal Research Center of the Russian Academy of Sciences, Studencheskiy Pereulok 3A, Samara, Russia
[2]Samara National Research University named after Academician S.P. Korolev, Moskovskoe Shosse 34, Samara, Russia

Abstract. The article presents the results of experimental studies on increasing the growth rates of three varieties of soft wheat *Triticum aestivum* (L.) after pretreatment of seeds with a pulsed magnetic field (PMF). The pulse effect shape is a damped sinusoid, the effect intensity is induction B = (0.53÷5.21) T, the effect duration is microseconds, the number of pulses n = 3 with an interval between them $\Delta\tau$= 3 s. Previously, the magnetic field effect with such parameters in crop production has not been studied. The greatest stimulating effect of the magnetic field is observed on wheat sprouts of the Tulaykovskaya Nadezhda variety: a statistically significant increase in the length of the sprouts by 3.4-3.6 times compared with the control. An assumption has been made about the mechanism of such a PMF effect on growth indicators: stimulation of oxidative stress in plants, increase in the concentration of mineral elements in the cell due to changes in membrane permeability. The ways of further research are determined.

1 Introduction

A large number of works have been published in crop production [1-10] devoted to the study of plant behavior after exposure to magnetic and electric fields. Thus, in [2] it is indicated that there are more than 40 physical methods of influencing seeds, including magnetic fields, to stimulate them to increase germination, growth, germination energy, enhance plant metabolism [3, 4], which entails improving product quality, accelerating maturation, increasing yields by 15-30%. A description of the effect of artificial magnetic fields on seed germination can be found in [5-7]. Thus, dry wheat seeds, after their preliminary magnetization, germinate more intensively than ordinary ones. In all these works, the effect on the plant of weak fields (mT), but long-term exposure (minutes, hours, days) was mainly studied. In [8, 11], studies have begun on the effect of pulsed magnetic fields of high intensity (more than 0.2 T) on seed germination.

It is of interest to evaluate the effect of higher-intensity PMF at B=0.53-5.21 T and microsecond duration on the growth rates of soft wheat *Triticum aestivum* (L.).

* Corresponding author: t.rodenko@mail.ru

2 Materials and Methods

Experimental studies on the PMF effect on growth indicators were conducted on three wheat varieties: "Integratsiya", "Tulaykovskaya Nadezhda", and "Skirda". The pretreatment of seeds with PMF was carried out in a test tube, which was placed in an inductor (coil) connected to a magnetic pulse unit (MIU-BIO-5). The MIU-BIO-5 capacitor bank, charged to a given energy, is discharged onto the inductor. An electromagnetic field arises around the coils of the inductor current line, which, penetrating through the tube wall, affects the seeds. The impact intensity is determined by the amount of energy W stored in the MIU-BIO-5 capacitor bank. Magnetic field induction was measured experimentally using an inductive sensor [12]. An example of PMF oscillogram is shown in Figure 1.

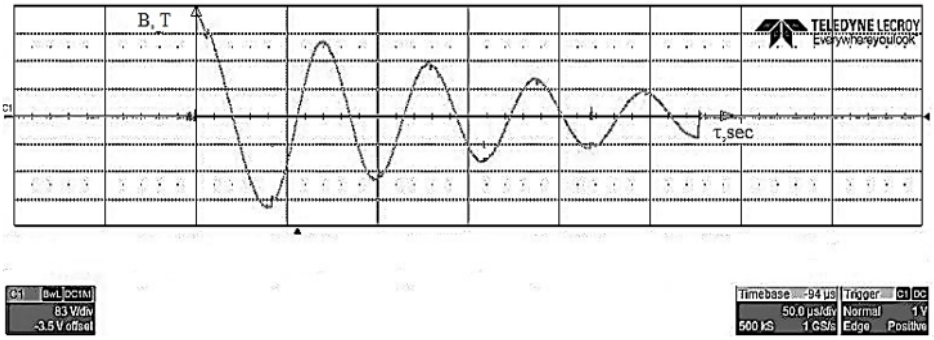


Fig. 1. PMF oscillogram. Induction B = 5.21 T. A single exposure.

Processing of the obtained oscillograms allowed to obtain the parameters of the magnetic pulse effect on seeds (Table 1). The range of parameters is determined by the level of energy used in the experiment.

Table 1. Parameters of magnetic pulse action on seeds of soft wheat *Triticum aestivum* (L.).

Energy W, kJ	Induction, T	Frequency, discharge current, kHz	Number of pulses, pcs.	Exposure time of one pulse, µs	Time between pulses (s)
0.07	0.53	15.7	3	44	3
0.54	2.21			160	
1.5	3.71			196.6	
2.94	5.21			333	

A multi-turn inductor with an inductance of L = 13.52 mH was used for seed treatment. The inner diameter is Ø 18 mm, the length of the working area is l = 120 mm (Figure 2).

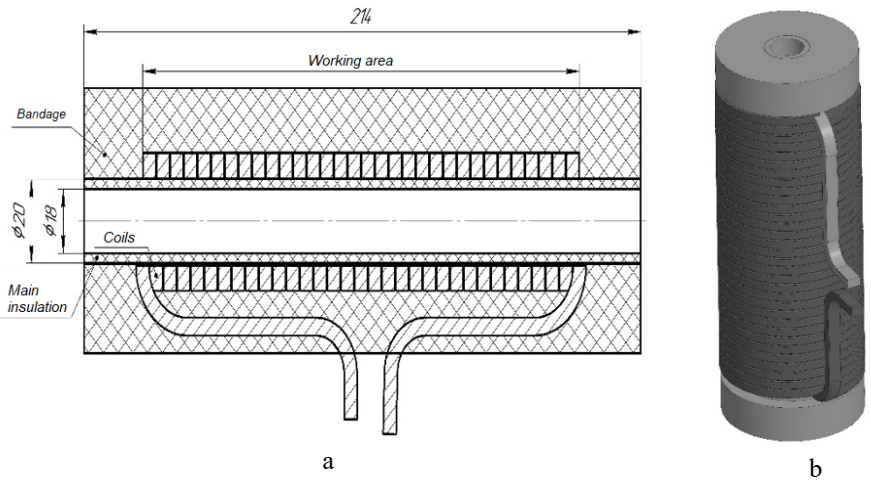


Fig. 2. The tool for pretreatment of wheat seeds is PMF: (a) – drawing, (b) – appearance of the inductor.

The seeds in the test tube should be placed in the coverage area of uniform magnetic field. To determine this zone extent, a measuring stand was created, including a low-frequency signal generator, a millivoltmeter, a Hall sensor, an oscilloscope, and a matching transformer.

Thus, as a result of the model experiment, a uniform magnetic field zone was determined (Figure 3), it was in this zone that the part of the test tube containing wheat seeds was placed.

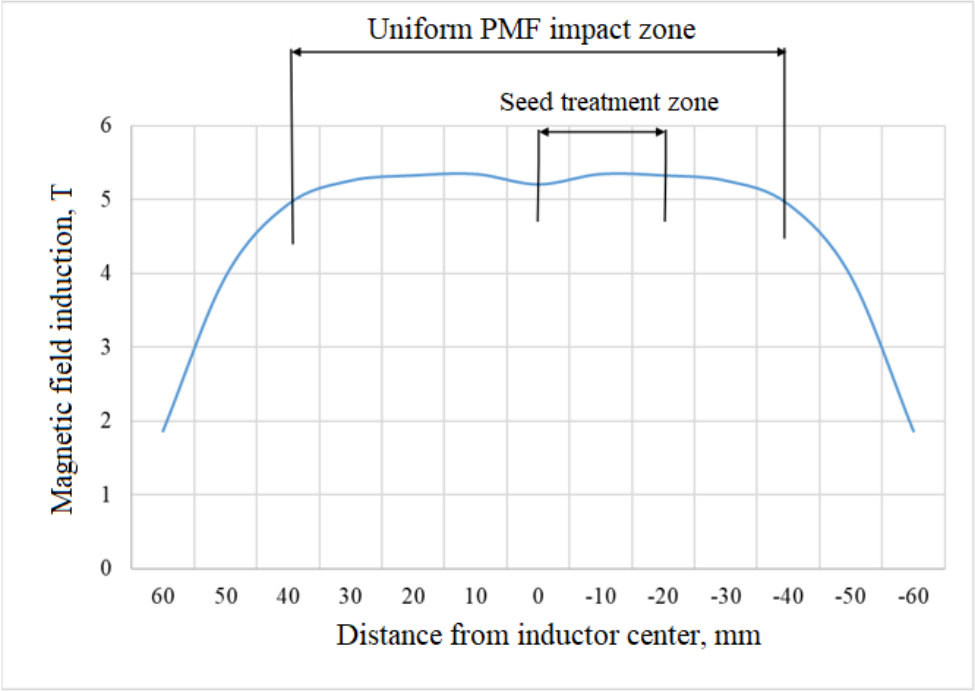


Fig. 3. The distribution of the electromagnetic field along the inductor axis.

The seed treatment scheme with PMF is shown in Figure 4. The inductor is connected to the MIU-BIO-5 magnetic pulse unit developed at the SamSC RAS. Its characteristics are shown in Table 2.

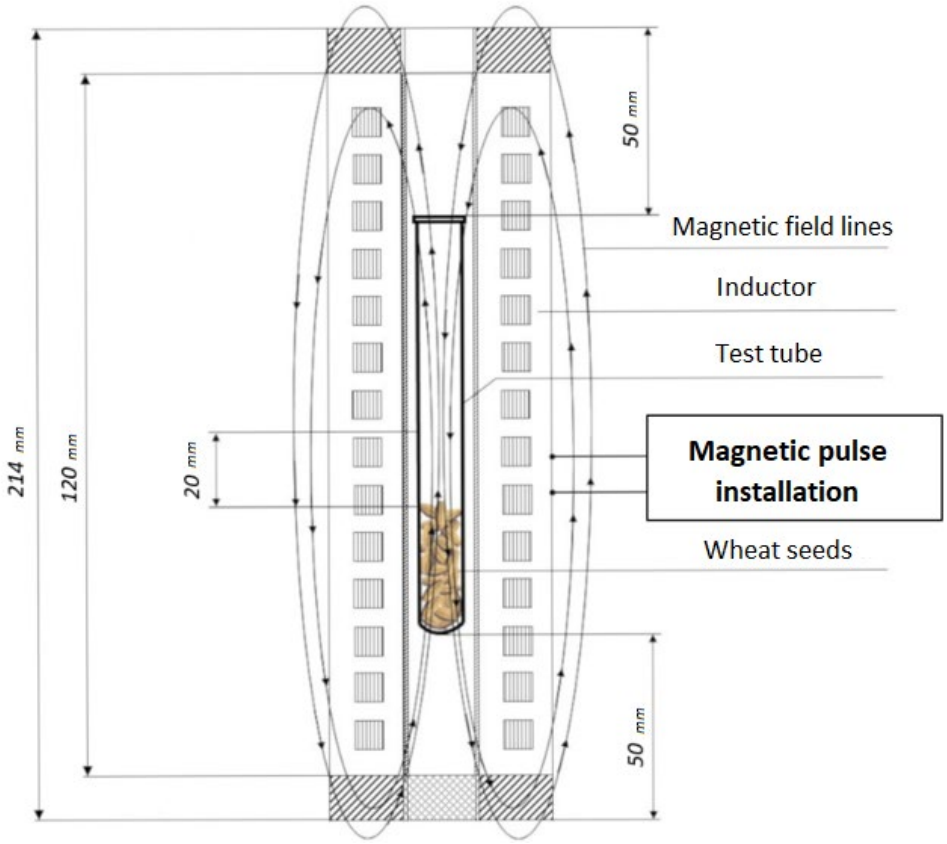


Fig. 4. Scheme of wheat seed treatment with PMF.

Table 2. Parameters of MIU-BIO-5.

Stored energy, W, kJ	Discharge voltage, U, kV	Current natural frequency, f, kHz	C_0, μF	L_0, μH
0.06…5.8	1…10	50	120	0.060

The originality of MIU-BIO-5 lies in the possibility of forming various pulse shapes and providing automatic discharge duty cycle from 1 to 10. The variable parameter in the experiment is the intensity of the magnetic field B = (0.53÷5.21) T. The control was an untreated batch of seeds located in the Earth's magnetic field (GMF)= $56.51 \cdot 10^{-6}$T.

Three batches of 250 wheat seeds in each were used in the experiment. The control batch also contained 250 pieces. After PMF exposure, wheat seeds were soaked in 2% $KMnO_4$ solution for 15 minutes, washed with distilled water, dried at room temperature for 60 minutes and transferred to germination in Petri dishes on filter paper discs abundantly moistened with distilled water. The germination experiment was carried out at a constant temperature of 22±2 ℃ with a 14-hour photoperiod. Seed germination was evaluated according to the method for determining seed germination (GOST 12038-84). On the third day, the seeds were moistened. Measurements of wheat germ length were carried out after 120 hours (on the fifth day) using a caliper with an accuracy of ±0.1 mm.

The experiments were performed in three biological repetitions. Statistical processing of the obtained data was carried out by the method of single-factor analysis of variance (Welch) in the jamovi 2.3.28 program. The differences were accepted as statistically significant at significance levels *p<0.05; **p<0.01, and ***p<0.001.

3 Results and Discussion

On the fifth day (120 hours) after the experiment on PMF effect on the seeds of three varieties of soft wheat *Triticum aestivum* (L.) in the range of inductions $B_{(av)}$ from 0.53 T to 5.21 T, an increase in the average length of sprouts (length of roots and shoots) was noted (Table 3).

Table 3. The PMF exposure effect on the biometric parameters of shoots and roots of three varieties of soft wheat *Triticum aestivum* (L.).

Factor	Length of shoots (av), cm	Root length (av), cm
"Integratsiya" variety		
Control (GMF = $56.51 \cdot 10^{-6}$T)	0.76±0.38	1.76±0.79
PMF, B=0.53 T (av)	0.4±0.40	1±0.91
PMF, B=2.21 T (av)	$1.1 \pm 1.03^{***}$	$1.88 \pm 1.72^{*}$
PMF, B=3.71 T (av)	$1.57 \pm 0.86^{***}$	$2.7 \pm 1.50^{**}$
PMF, B=5.21 T (av)	$1.67 \pm 0.97^{***}$	$2.64 \pm 1.50^{**}$
"Tulaykovskaya nadezhda" variety		
Control (GMF = $56.51 \cdot 10^{-6}$T)	0.59±0.37	0.69±0.42
PMF, B_{av}=0.53 T	$1.87 \pm 1.23^{***}$	$2.53 \pm 1.53^{***}$
PMF, B_{av}=2.21 T	$2.05 \pm 1.44^{***}$	$2.55 \pm 1.75^{***}$
PMF, B_{av}=3.71 T	$1.93 \pm 1.46^{***}$	$2.36 \pm 1.70^{***}$
PMF, B_{av}=5.21 T	$1.99 \pm 1.47^{***}$	$2.41 \pm 1.77^{***}$
"Skirda" variety		
Control (GMF = $56.51 \cdot 10^{-6}$T)	2.76±1.60	3.74±1.96
PMF, B_{av}=0.53 T	2.36±1.48	3.4±2.12
PMF, B_{av}=2.21 T	2.77±1.63	3.54±2.28
PMF, B_{av}=3.71 T	2.04±1.61	3.01±2.24
PMF, B_{av}=5.21 T	$3.57 \pm 1.40^{**}$	$5.43 \pm 2.30^{**}$

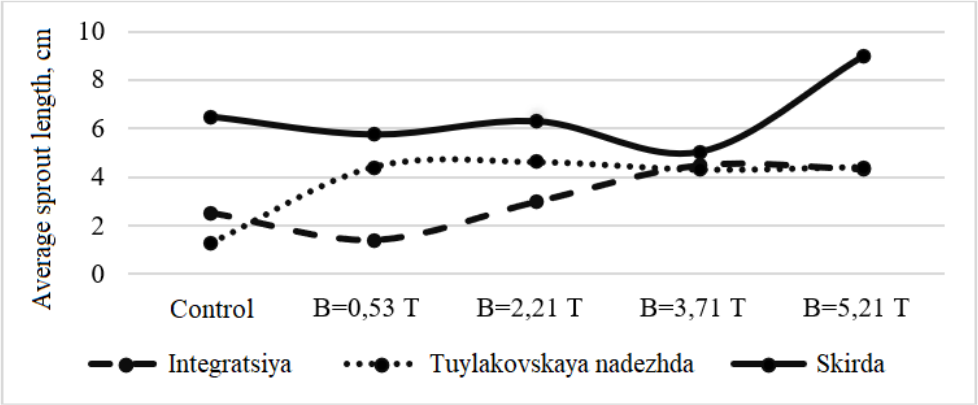
Hereafter $*p < 0.05$; $**p < 0.01$; $***p < 0.001$.

The table shows that the average length of shoots of the Tulaykovskaya Nadezhda wheat variety when exposed to PMF in all modes with inductions B_{av} =(0.53÷5.21) T increased by 3.2-3.5 times compared with the control. Stimulation of the length of shoots by 1.4-2.2 times compared with the control group was also observed on wheat seeds of the "Integratsiya" variety in the range of PMF inductions B_{av}=(2.21÷5.21) T. The treatment of wheat seeds of the "Skirda" variety showed an increase in the length of shoots by 1.3 times only when treated with a maximum induction of B_{av} = 5.21 T.

The PMF effect on wheat seeds of the Tulaykovskaya Nadezhda variety in all modes with induction B_{av} = (0.53÷5.21) T contributed to root stimulation by 3.4-3.7 times compared with the control. An increase in root length by 1.1-1.5 times was observed when exposed to wheat seeds of the "Integratsiya" variety with inductions B_{av}=(2.21÷5.21) T. Nevertheless, a 1.5-fold increase in root length during magnetic pulse treatment for the wheat variety "Skirda" was shown only with induction B_{av} = 5.21 T.

Using the experimental data obtained (Figure 5) on the treatment of soft wheat seeds with PMF in relation to the Tulaykovskaya Nadezhda wheat variety, a statistically significant increase in the length of sprouts (length of roots and shoots) was noted by 3.4-3.6 times compared with the control under all modes of exposure to a magnetic field with inductions in the range B_{av} =(0.53 ÷5.21) T. During PMF processing of wheat seeds of the "Integratsiya" variety, a statistically significant increase in the length of the shoots was revealed by 1.1-1.7

times with induction B_{av} =(2.21÷5.21) T. Nevertheless, the PMF effect on wheat seeds of the "Skirda" variety showed a statistically significant increase in the length of sprouts by 1.4 times compared with untreated seeds only at maximum magnetic field induction B_{av} = 5.21 T.



Note: statistically significant differences from the control at significance levels **p <0.01 and ***p <0.001.

Fig. 5. The effect of a pulsed magnetic field on the length of the sprouts of soft wheat *Triticum aestivum* (L.).

From the graphs shown, it can be seen that PMF has a stimulating effect on plant growth (Table 4).

Table 4. The ratio of the length of the sprouts of the seeds treated with PMF to the length of the sprouts of the control group seeds.

Wheat variety	Induction B, T	Ratio of the length of the sprouts to the length of the control batch sprouts
Integratsiya	0.53	0.56
	2.21	1.18
	3.71	1.69
	5.21	1.71
Tulaykovskaya Nadezhda	0.53	3.44
	2.21	3.59
	3.71	3.35
	5.21	3.44
Skirda	0.53	0.89
	2.21	0.97
	3.71	0.78
	5.21	1.38

Thus, the PMF effect on wheat seeds in the range of inductions B_{av} =(0.53÷ 5.21) T is more pronounced in the Tulaykovskaya Nadezhda wheat variety, processing improves wheat growth indicators, while no negative effects are observed (violation of root formation, deformation of sprouts, etc.).

To explain the reasons for the increase in wheat growth rates after PMF pretreatment of seeds, allowed to make assumptions about the mechanisms leading to such an effect: changes in the electric transport chain of chloroplasts and mitochondria; stimulation of oxidative stress in plants through increased generation of superoxide anion and, accordingly, an increase in the activity of superoxide dismutase (SOD); increased permeability of membranes for ion transport, which leads to increase in the concentration of mineral substances.

The possibility of implementing such effects and their effect on growth characteristics was reported in [13, 14]. The study of the proposed mechanisms is a prospect for further research.

Thus, stimulation of soft wheat seeds of *Triticum aestivum* (L.) with PMF leads to an increase in their germination, therefore, magnetic effect can be used as a non-invasive external stimulator of seed germination. Pulsed magnetic fields in pre-sowing treatment can be used to increase seed productivity, which will make it possible to apply this processing method for commercial purposes.

4 Conclusions

The fact of PMF stimulating effect at B=0.53-5.21 T and with a microsecond duration on the growth indicators of soft wheat *Triticum aestivum* (L.) has been established.

There was an increase in the growth rate by 3.4 times at B=0.53 T, 3.6 times at B=2.21 T, 3.4 times at B=3.71 T and 3.4 times at B=5.21 T for the Tulaykovskaya Nadezhda wheat variety.

It has been suggested about the causes of such a reaction of plants to PMF effects at B=0.53-5.21 T and with microsecond duration, which is the direction of further research.

The positive effect of PMF on wheat growth and germination (as previously shown) opens the way to the commercial use of the proposed method of stimulating plant development. The time of PMF pretreatment of seeds is reduced to a few seconds.

References

1. N. Hirota, J. Nakagawa, K. Kitazawa, J. Appl. Phys., **85**, 5717-5719 (1999) https://doi.org/10.1063/1.370262
2. A.V. Klochkov, O.S. Klochkova, O.B. Solomko, Bulletin of the Belarusian State Agricultural Academy, **3**, 163-168 (2020)
3. D.A. Normov, D.A. Ovsyannikov, *Electrozoning in agriculture* (Krasnodar, 2008) 311
4. I.G. Sidortsov, *Increasing the effectiveness of the effect of a constant magnetic field on grain seeds during their pre-sowing treatment*: abstract (Zernograd, 2008) 19
5. R. Radhakrishnan, Physiol Mol Biol Plants, **25**, 1107-1119 (2019). https://doi.org/10.1007/s12298-019-00699-9
6. A.P. Dubrov, *Geomagnetic field and life* (L.: Hydrometeoizdat, 1974) 176
7. A.Y. Izmailov, I.G. Smirnov, D.O. Khort, R.A. Filippov, A.I. Kutyrev, Res. Agr. Eng. **64**, 181-186 (2018) https://doi.org/10.17221/9/2018-RAE
8. V. Novickij, A. Grainys, I. Kucinskaite-Kodze, A. Zvirbliene, J. Novickij, IEEE Trans. Magn. **51**, 5000505 (2015). https://doi.org/10.1109/TMAG.2015.2439638
9. J. Bhardwaj, A. Anand, S. Nagarajan, Plant Physiol. Biochem., **57**, 67-73 (2012). https://doi.org/10.1016/j.plaphy.2012.05.008
10. V.A. Syrkin, T.S. Gridneva, P.V. Kryuchin, S.V. Mashkov, S.I. Vasiliev, Bulletin of Agrarian Science of the Don., **42**, 2 (2018)
11. T.I. Vasilyeva, N.A. Rodenko, V.A. Glushchenkov, Proceedings of the Samara Scientific Center of the Russian Academy of Sciences. Agricultural sciences, **1**, 3-10 (2023)
12. V.A. Glushchenkov, *Inductors for magnetic pulse processing of materials* (Educational literature, Samara, 2013)

13. E.A. Vasilyeva, Yu.V. Sinitsyna, E.O. Polovinkina, E.S. Yashina, A.P. Veselov, Bulletin of the NNSU, **2**, 174-177 (2011)
14. V. Novickij, J. Dermol, A. Grainys, M. Kranjc, D. Miklavčič, PeerJ., **5**, 4 (2017) https://doi.org/10.7717/peerj.3267