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Effect of magnetic field on germination and yield of wheat

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A b s t r a c t. The effect of magnetic field on germination and yields of spring wheat is presented. In the performed experiment two magnetic doses: D11=D13= 12.9 and D21=D23=17.9 kJ m^{-3} s were applied. The germination kinetic and yield of wheat depended on both magnetic field exposure doses. In both cases the better germination of seeds as compared to control seeds was observed. The yield of wheat for the exposure doses D11=D13 was 12.5% higher and for doses D21=D23 was 14.5% higher than obtained for the control.

K e y w o r d s: magnetic field, wheat, pre-sowing treatment, germination, yield

INTRODUCTION

The germination, growth, yield and quality of crops are determined by the properties of seed material, which can be improved by pre-sowing treatment with the involvement of various physical factors such as the electric field, magnetic field, laser radiation and microwave radiation. Physical methods applied in the treatment of greenhouse plants include also the use of magnetically treated water. The pre-sowing stimulation of seeds with a magnetic field may involve a constant magnetic field produced by permanent magnets and electromagnets as well as a variable magnetic field. A variable magnetic field is produced by specially designed electromagnets. In general, magnetic fields speed up seed germination and plant growth. The intensity of the applied magnetic fields and the time of seed exposure vary greatly.

In an experiment involving a very weak constant magnetic field of 0.5mT, Novitsky *et al*. (2001) noted an increase in leaf size as well as higher protein and chlorophyll levels in onion sets. By subjecting maize seeds to a constant magnetic field of 150 mT, Aladjadiyan (2007) reported an increase in the growth rate of stems and attained higher yields under the influence of magnetic fields with the intensity of 60-200 mT. Spanish researchers investigated rice and barley seeds. Carbonell *et al*. (2000) noted higher rice seed germination rates under the influence of 150 and 200 mT magnetic fields as well as higher yields of barley subjected to a magnetic field with the intensity of 125 mT with exposure time of 24 h (Martinez *et al*., 2000). Atak *et al*. (2003) subjected soybean seeds to constant magnetic fields of 2.9-4.6 mT and noted accelerated root growth as well as an increase in the levels of chlorophyll a and b.

Rochalska and Grabowska (2007) demonstrated that a variable magnetic field of 16 Hz, 5 mT, lowers the activity of alpha-amylase and beta-amylase enzymes in wheat. Aksenov *et al*. (2001) noted an increase in the growth rates of wheat roots and germs under the influence of a 50 Hz, 30 mT magnetic field. The effect of a weak magnetic field with the intensity of 20 μT and frequency of $16\frac{2}{3}$ Hz increased the weight and height of sunflower plants and enhanced wheat germination rates (Fischer *et al*., 2004). Ratushnyak *et al*. (2008) demonstrated that high frequency magnetic fields of 30-60 GHz with a stream of 10^{-16}-10^{-10} W cm^{-2} and exposure time of 5-15 min stimulated the growth of microflora in pine seeds.

The above data indicate that the results noted at various research centers are difficult to compare. Difficulties are also encountered when interpreting the results of pre-sowing stimulation of seeds with an electric field. This is related to a very broad range of intensity of magnetic fields and varied exposure times. A common unit of measure has been proposed to facilitate a comparison of the results reported by various research centers, namely the exposure dose which accounts for the effect of magnetic and electric fields as well as the time of exposure (Pietruszewski, 1999; Pietruszewski *et al*., 2007). The exposure dose is the product of magnetic (electric) field density and exposure time. The density of a magnetic field (ρ) or an electric field is determined with the use of the following formula:

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$$\rho = \frac{1}{2}\varepsilon_0 E^2 = \frac{1}{2}\mu_0 H^2 = \frac{1}{2\mu_0}B^2, \quad (1)$$

where: ε_0 – vacuum permittivity, μ_0 – vacuum permeability, E – electric field intensity, H – magnetic field intensity, B – magnetic induction.

The exposure dose is described by the following dependence:

$$D = \rho t, \quad (2)$$

where: t – exposure time.

The magnetic exposure dose would facilitate a comparison of the results reported by various research centers to improve the quality of seed material.

The aim of this work was to check whether application of pre-sowing stimulation of winter wheat seeds with variable magnetic fields of different exposure time and doses influence the germination kinetics and the final crop yield.

MATERIALS AND METHODS

Experiments involving two exposure doses in the pre-sowing stimulation of winter wheat seeds with a magnetic field were carried out by the Faculty of Physics at the University of Life Sciences in Lublin. The study investigated germination kinetics, and the obtained results were validated in a field study. Four days after the final stimulation, the seeds were sown in experimental plots in the amount of 600 kernels per m^2 in five replications, including control. The experiment was carried out at the Experimental Farm in Felin near Lublin. The crop was harvested manually.

Exposure doses were determined with the use of two methods (Table 1). Dose D13 was produced by applying a variable magnetic field with induction of 30 mT and an exposure time of 6 s for 3 successive days. An identical dose of D11 was obtained at an induction level of 45 mT and an exposure time of 8 s. Dose D23 was produced by applying a 30 mT field with an exposure time of 8 s over 3 successive days, while dose D21 was obtained at an induction level of 60 mT and an exposure time of 8 s.

Physical factors affect seed germination, including not only germination capacity but also germination kinetics. The germination kinetics of seeds stimulated with a magnetic or electric field before sowing is most often described using the Malthus-Verhulst equation (Pietruszewski, 2001):

Table 1. Parameters of the magnetic exposure dose

Dose	Day 1	Day 2	Day 3	Dose value (kJ m^{-3} s)
D11			45 mT, 8 s	12.9
D13	30 mT, 6 s	30 mT, 6 s	30 mT, 6 s	12.9
D21			60 mT, 8 s	17.2
D23	30 mT, 8 s	30 mT, 8 s	30 mT, 8 s	17.2

$$N(t) = \frac{N_k}{1 + (N_k - 1)\exp[\alpha N_k (t - t_0)]}, \quad (3)$$

where: $N(t)$ – number of seeds that germinated within time t, N_k – final number of germinated seeds, α – germination rate coefficient, t_0 – time required for the first seed to germinate.

Germination rate can be determined based on the logistic curve (Pietruszewski, 2002):

$$\nu_k = \frac{dN(t)}{dt} = N(t)\alpha[N_k - 2N(t)], \quad (4)$$

where: ν_k – germination rate.

The germination process of stimulated seeds can be modeled using the logistic curve and the germination rate curve, and curve fitting errors do not exceed 8%. The differentiation of Eq. (4) followed by equating it to zero provide a basis for determining the extremum (maximum) of germination rate and the time needed to reach this value:

$$\frac{d^2 N(t)}{dt^2} = \alpha N(t)[N_k - N(t)][N_k - 2N(t)], \quad (5)$$

$t = t_{max}$ for $N_k = 2N(t)$, therefore:

$$t_{max} = \frac{\ln(N_k - 1)}{\alpha N_k}. \quad (6)$$

RESULTS

The germination kinetics of wheat seeds was determined using an electronic seed germinator counting the number of germinated seeds (Patent P-343612). The germination kinetics curves are shown in Fig. 1. As seen from the presented figures pre-sowing stimulation with magnetic field accelerates the process of germination of winter wheat seeds. The germination of control sample is considerably postponed. The differences between samples are explicitly manifested 20 h after sowing.

The curves were described based on logistic curve Eq. (3) and were presented in graphic form (Fig. 2). Equations (4) and (6) were used to calculate the logistic curve parameters given in Table 2.

For exposure dose D11=D13, the germination rate coefficients were found to be identical, while the maximal germination rates and time required to reach the maximal germination rate varied within the limits of measurement accuracy. For exposure dose D21=D23, the germination rate coefficients were different, but the values of the other parameters remained within the limits of measurement accuracy. The parameters of the logistic curve for the control sample differ significantly from these parameters estimated for D11=D13 and D21=D23 doses. This is apparently visible for the parameter, amounting 0.005155, 0.007626 and 0.005855 respectively for control and the doses of different exposure times. The calculated maximal speeds of germination are also significantly different. For D11 dose the increase of maximal speed of germination amounts 60% and for D23 dose 27.6%.

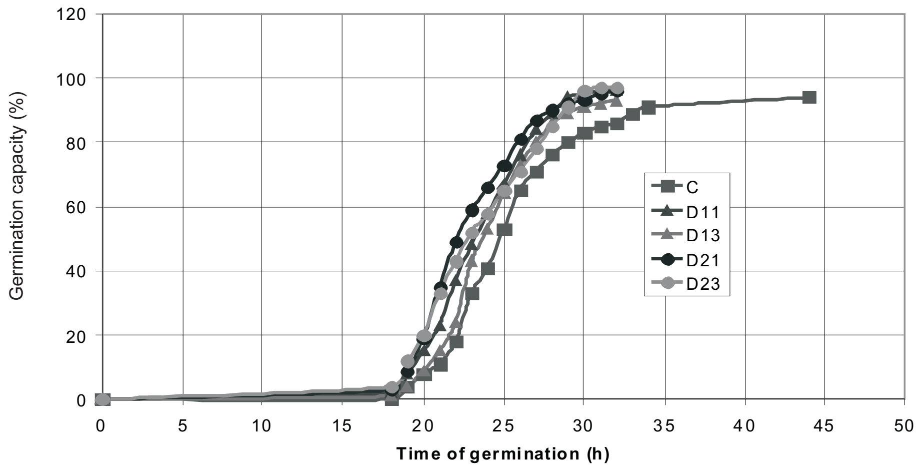

Fig. 1. Germination kinetics determined with the use of an electronic seed germinator.

a

b

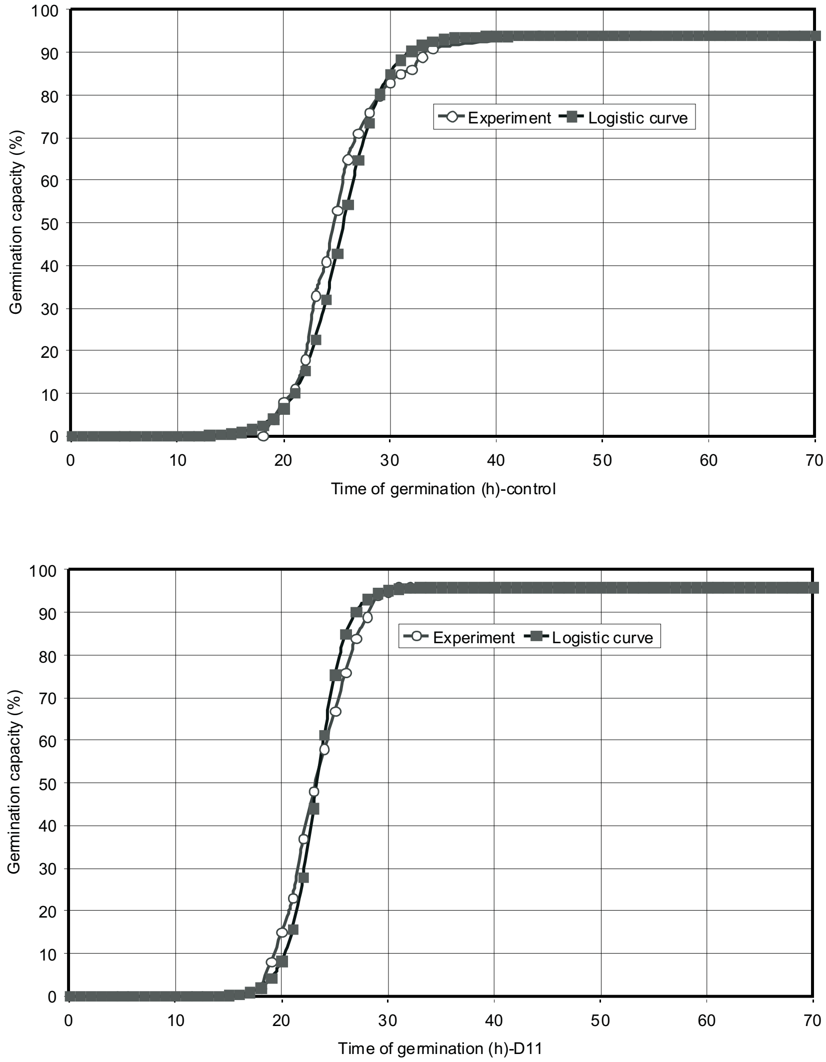

Fig. 2. Experimental data and the logistic curve for: a – control treatment; and doses: b – D11, c – D13, d – D21, e – D23.

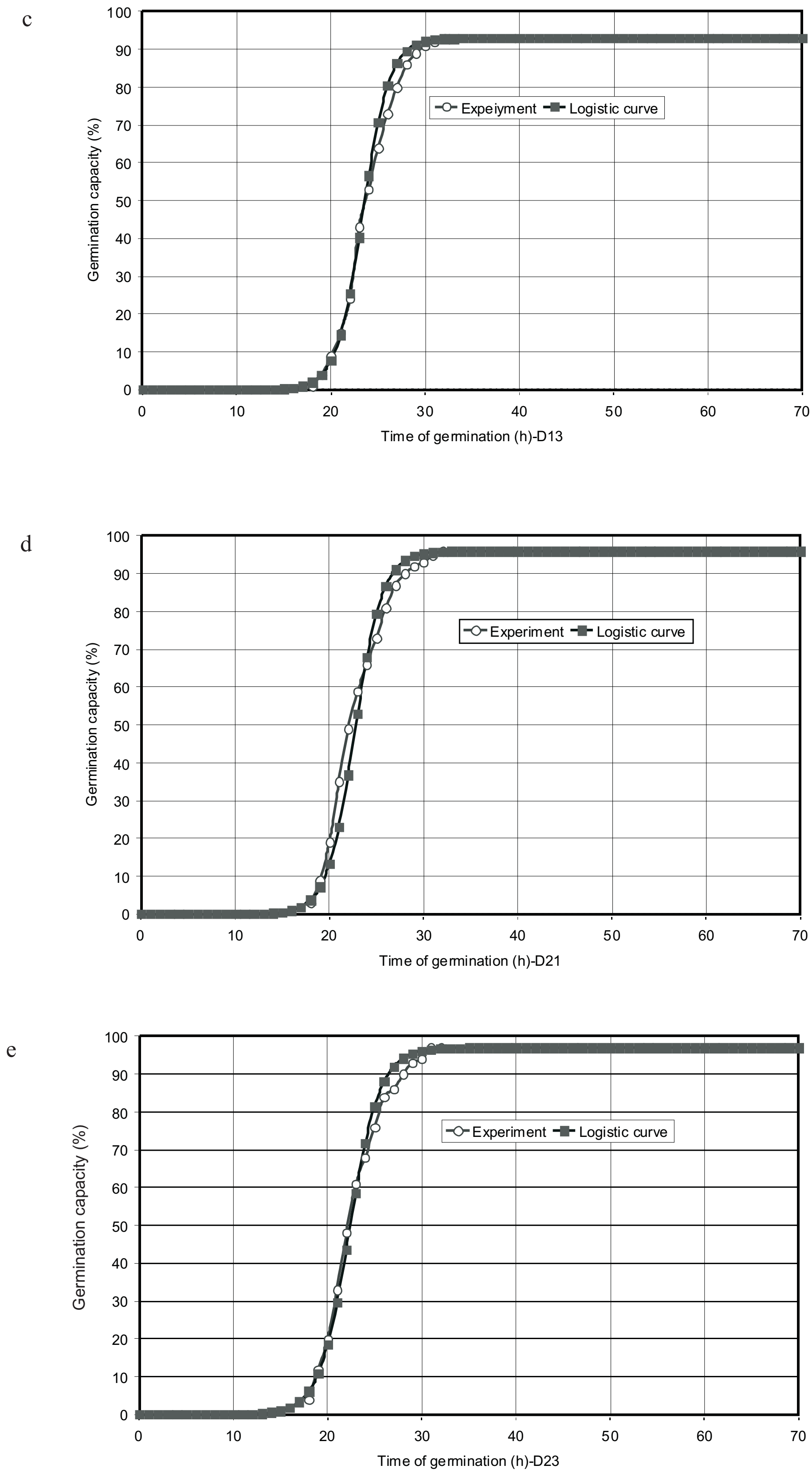

Fig. 2. Continuation.

T a b l e 2. Parameters of the logistic curve

Dose	N_k (%)	t_0 (h)	α (1/% h)	t_{max} (h)	V_{kmax} (%/h)
C	94	16	0.005155	25.35±1.17	10.9±0.9
D11	96	17	0.007625	23.22±1.16	17.5±0.8
D13	93	17	0.007625	23.36±1.16	16.5±0.8
D21	96	16	0.007085	22.70±1.14	13.6±.07
D23	97	15	0.005855	23.01±1.15	13.7±0.7

T a b l e 3. The effect of the pre-sowing exposure dose on yield parameters after a statistical evaluation

Parameter	Exposure dose					LSD
	Control	D11	D13	D21	D23	
Spike length (cm)	5.72 a	6.74 b	6.78 b	7.32 c	6.66 b	0.87
Number of spikes per m^2	505 a	522 b	526 b	536 b	537 b	13.7
Yield per m^2	369 a	448 b	476 b	514 c	557 c	38.3
Culm height (cm)	70 a	82 b	85 b	86 b	83 b	3.7

a, b, c – means in the same row with the same letters are not significantly different.

The collected crop was measured to determine spike length, the number of spikes per m^2, yield per m^2 and culm height. Culm height was measured at five locations in each experimental plot before harvesting. The results were processed statistically to determine the significance of differences. A collective presentation can be found in Table 3.

The results of this study indicate that the attained yield was affected by the exposure dose regardless of the method by which it was determined. Pre-sowing magnetic exposure dose resulted in a significant increase of the length of the spikes by 18.5 and 27.9%, respectively for the D13 and D21 doses as compared to control. The numbers of spikes per square meter estimated for all the exposure doses are not statistically different but higher by 10% as compared to control. The crops obtained from 1 m^2 for the D11 and D13 doses are also higher by 25% from the control but they do not show any statistical differences between themselves. The crops obtai- ned from 1 m^2 for the D21 = D23 doses are comparable but higher by 45% from the control.

No statistically significant differences in yield parameters were observed for the same exposure doses. The higher yield increase noted for doses D21 and D23 resulted from a higher number of spikes per m^2. The obtained results also suggest that the magnetic field does not exert a selective effect. It increases germination rates, spike length as well as overall plant height. The plant height for all the exposure doses is on average 20% higher than the height of the control plants. This latest feature is however not much desirable because the plants of greater heights may be much more susceptible to lodging.

The results obtained at various research centers, regarding the effect of a magnetic field on seeds and plants, are extremely difficult to compare. According to recent literature data, the intensity of the applied magnetic fields ranges from 20 μT to over 200 mT. Constant magnetic fields, variable magnetic fields (50-60 Hz, 16 Hz) as well as high-frequency magnetic fields (30-60 GHz) are used. Therefore, a common unit of measure has been proposed, namely the exposure dose which accounts for the effect of a magnetic field as well as the time of exposure. This effect is dependent upon the energy of a magnetic field and exposure time. Thus, the exposure dose can be described as the product of magnetic field density and exposure time. The energy absorbed by seeds and plants has not been determined to date.

CONCLUSIONS

1. The pre-sowing magnetic stimulation of the seeds results in acceleration of the process of germination.

2. The parameters of the germination curve (logistic curve) are comparable for the stimulated seeds and irrespective of the exposure dose applied.

3. The crops obtained from the pre-sowing stimulated seeds are higher as compared to control and irrespective of the exposure dose applied.

4. Pre-sowing magnetic exposition dose is the parameter which may determine the influence of the magnetic field on germination and the final crop yield of the winter wheat.

5. The obtained results validated the hypothesis that the impact of a magnetic field on wheat yield and germination capacity is affected by the exposure dose defined by Eq. (2), regardless of the method by which it was determined.

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