EFFECTS OF STATIC ELECTROMAGNETIC FIELDS AT 24 HOURS INCUBATION ON THE GERMINATION OF ROSE COCO BEANS (*PHASEOLUS VULGARIS*)

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Abstract. This study evaluates the percent germination of Rose coco beans (*Phaseolus vulgaris* L.) seeds, when exposed to static electromagnetic fields under laboratory conditions incubated for 24 h. This can be replicated in the field to aid short period production of beans, hence higher yield. For a given set of sample, germinating bean seeds were exposed to field generated by Helmholtz coil, North Pole or the South Pole with constant magnetic fields of 5 mT, 10 mT, 30 mT and 60 mT. The exposure period was fixed at 3, 4.5 and 6 h and exposed after 12 h incubation. The germinating seeds were counted after 24 h. Certain trends could be observed; statistical analysis has shown that there is statistical influence ($p < 0.05$, ANOVA test) of the magnetic treatment on germination of rose coco beans. Maximum seed germination occurred when exposed to South Pole field inducing percent germination of approximately 73% compared to 52% of the control at field strength of 30 mT at exposure period of 4.5 h. The research achieved its aim of proving the influence of static electromagnetic field to germination of seeds in addition to, challenging seed companies to come up with magnetized seeds that will germinate faster.

Key words: Germination, static electromagnetic fields, incubation period.

INTRODUCTION

Bean (*Phaseolus vulgaris* L.) is the major source of protein in the world especially for the poor people [17]. This is because animal protein is very expensive to ordinary Kenyans, most of them, earning below one United States dollar per day. The major variety of common beans grown in Kenya is the "Rose coco" type, cultivated on about 700,000 hectares due to their adaptability, attractive market prices, taste and good cooking properties [17]. Poor farming methods have led to low productivity of beans. Furthermore, different chemical additives are used for raising productivity of beans. Their application may contaminate produced

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beans with toxins that are dangerous to consumers' health. Developing and implementing new methods for higher productivity and quality assurance when growing beans in Kenya is needed. Investigating the effect of varied static electromagnetic fields on germination of Rose coco beans is the genesis.

Whether plants respond to magnetic field is a subject under investigation. Earlier studies on the effects of static fields on germination of plants are summarized in Table 1.

Table 1

Summary of previous researches involving static magnetic fields

Seed	Magnetic field strength and period	Effect of exposure	Ref.
Oak (aka, acorns) seeds	Weak electromagnetic fields (WEF)	Increase in germination	[8]
Onion and Rice	WEF for 12 h	Significantly increased germination	[5]
Lettuce	Stationary magnetic field of 0–10 mT	A significant increase in the rate with which the seeds absorb water; Increase of germination rate of the seeds	[20]
Castanea sativa Mill	Static magnetic field	No effects	[21]
Barley	Homogeneous magnetic field	Small, consistent, but statistically insignificant germination, accompanied by significant increases in variability	[14]
Rice	150 and 250 mT, exposed chronically and for 20 min	Chronic exposure to a 150 mT magnetic field significantly increased germination Significant differences for seeds exposed to 250 mT for 20 min, dynamic and static treatment of water improved the germination	[7]
White Mustard	Permanent magnet exposed continuously for 4 days	Increased germination	[10]
Wheat, Barley and Oat	0.05 T to 0.30 T	Positive effect on germination rate	[6]
Maize	5 kgauss	25 % increase in root growth	[13]
Maize	0.15 T exposed for 10, 15, 20 and 30 minutes	Increase in germination and germination energy	[4]
Potato	WEF	Positive effects on the tuber formation	[19]
Various seed	Magnetic or electromagnetic	Seed germination was accelerated	[18]
Tomato	Field of 0.08, 0.1 and 0.17 T	Increased the germination by 5 to 25%	[9]
Maize	Field of 0.08, 0.1 and 0.17 T	Increased the germination	[11]
Soybean, maize, peas, okra, and beans	Pre-sowing treatment with a magnetic field	Positive impact on germination	[16]

Table 1 (continued)

Asparagus originalis L.	Static magnetic field	Increase in germination	[23]
Tobacco	0.15 T exposed for 10, 15, 20 and 30 minutes	Increase in germination	[2]
Soybean	0.15 T exposed for 10, 15, 20 and 30 minutes	Increase in germination	[3]

The influence of magnetic field treatment on tobacco seeds concluded that germination depends on the induction of the field (magnetic field strength), exposition of the samples (period sample is exposed to given field strength) and the pre-history of the samples (sample species of plant) [2]. It has been noted that environmental conditions (temperature, humidity, etc.) influence germination during magnetic field application [6]. The main objective of this study was to determine whether static magnetic field has any effect on the germination of beans in Kenya, given its position around the equator. Investigating and determining the effective exposure time and magnetic field that achieves the highest percent of germination for germinating bean seeds allow further research in applying static magnetic field for developing quality seeds and producing uncontaminated yield.

MATERIALS AND METHODS

INSTRUMENTS

The instrument used in measuring magnetic flux density was a magnetic flux density unit (model Unilab 612.002) connected to a multimeter (model ALDA AVD830B). A variable transformer supplied power (model UNILAB, low voltage power unit 022.317: 0–25 V, 8.5 A rms max). The Helmholtz coil used was the model PHWE 06990.10; 320 turns, diameter 14 cm.

CALIBRATION OF MAGNETIC FLUX DENSITY UNIT

Magnetic flux density unit was calibrated using Group3 DTM-151 Digital teslameter with IEEE-488 GP1B Interface and DTMG V6 software. This teslameter was supplied with power from a Danfysik model system 8000. Magnetic field was produced by a 100 mm electromagnet GMW model 3472-70.

For calibrating the magnetic flux density, first the output portion of the magnetic flux density unit was connected to the two terminals of the multimeter with the multimeter measuring scale being in the mV knob so as to record any voltage output generated by the magnetic flux density unit. It was then fixed to the power supply. On the other hand, the digital teslameter with its interface was connected to the Software. This teslameter was supplied by power from Danfysik model system 8000. This circuit is shown in the schematic diagram in Fig. 1.

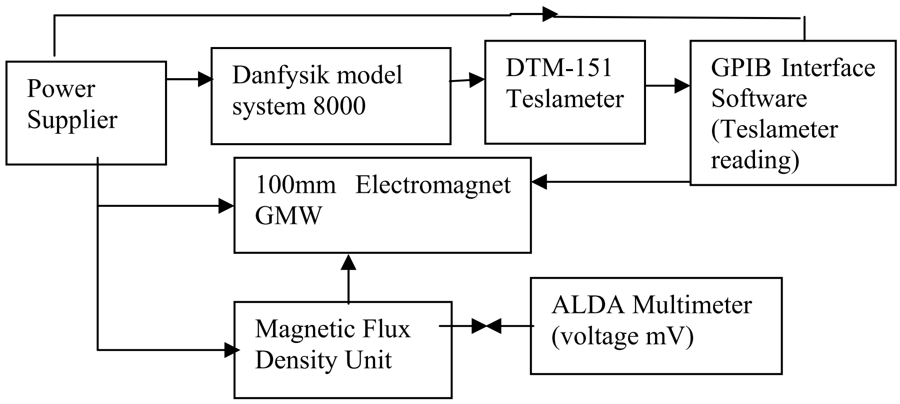

Fig. 1. Schematic diagram illustrating calibration of magnetic flux density unit.

After fixing the magnetic flux density unit to a maximum of 1000 mT position, the power was switched on, on both the magnetic flux density unit and the Danfysik model system 8000. The probes of both the digital teslameter and the magnetic flux density unit, side by side, were inserted in the middle of the electromagnet. The background magnetic field was recorded by the teslameter while the flux density voltage output was also recorded. By controlling the amount of current supplied to the electromagnet one varied the strength of the field and its value was recorded as voltage output using the ALDA model multimeter. Table 2 gives the results obtained.

Table 2

Teslameter recording and the corresponding multimeter voltage through the magnetic flux density unit

		Attempts				
	Background	1	2	3	4	5
Teslameter readings (mT)	3.28	10.09	16.90	23.73	30.57	37.40
Flux density (mV)	–5	5	16	26	37	47

For a fixed strength value of a magnetic field, the probe of the flux density unit was placed in a position in which the field was to be determined and also the value of the voltage used in determining the field strength. The strength of the fields at 5, 10, 30 and 60 mT was determined from voltage (Fig. 2) and fixed at 10, 13, 26.2 and 46 mV, respectively.

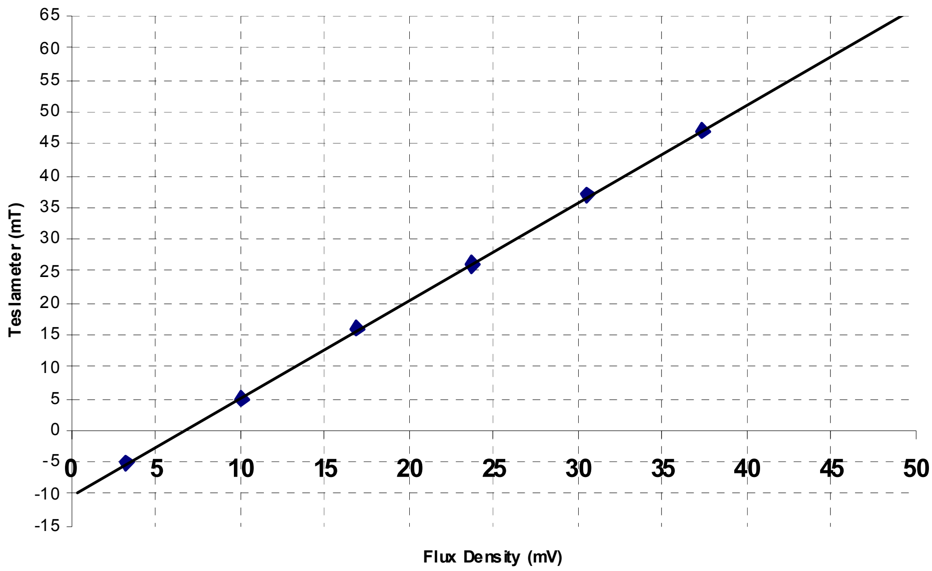

Fig. 2. Flux density versus B-field as per teslameter reading.

SOURCE OF BEAN SEEDS AND THEIR PREPARATION

Two kilograms of viable Rose coco GLP-2 seeds were bought from Kenya Seed Company. The seeds of nearly the same size and colour were selected and grouped in tens. Beans were then soaked for one hour in distilled water. Each group of 10 soaked seeds was then placed in a Petri dish lined with a lean sheet of absorbent tissue paper. A blotting paper was used to cover the seeds and distilled water was sprinkled on top. For one such set of experiments, four Petri dishes were prepared and labeled as follows: H – Field produced by Helmholtz coil; N – Field produced by the North Pole; S – Field produced by the South Pole; C – Control.

SOLENOID PREPARATION

A cuboid soft magnetic material made of soft iron, whose thickness is a square of 1 cm and length 50 cm, was used. This soft magnetic material was wound 700 times on each side by a coated copper wire. This solenoid provided the North Pole on the one side and the South Pole on the other side. A Perm alloy was placed in the middle to prevent the effect of one pole to the other. Varying the amount of current resulted in the desired field strength as plotted in Fig. 2.

EXPERIMENTAL SET-UP

Magnetic field strength for the Helmholtz coils was set at 5 mT with the aid of a magnetic flux density unit (PHWE 612.002) and by varying the current in the coil. Petri dish H was placed in between the two pairs of Helmholtz coils, 12 h after inception of the experiment. For the next 3 h the beans in Petri dish H were exposed to the Helmholtz static field set at 5 mT. The Petri dish C served as a control under the same conditions except for the fact that it was not exposed to a magnetic field. Germination was considered to take place once the tip of the radicle (1–2 mm) has emerged from the seed [15]. The number of germinating seeds was counted and recorded after 24 h. The magnetic field strength was increased from 5 mT to 10 mT, 30 mT and finally 60 mT and the above procedure was repeated for each case. Exposure time was varied from 3, 4.5 and 6 hours for each set magnetic field. The experiments were replicated three times. The same procedure was followed for seeds exposed to North Pole and South Pole fields. It should be noted that apart from using clockwise rule in determining the polarity of the electromagnet (solenoid), a permanent magnet's repulsion was used to ascertain the polarity.

DATA ANALYSIS

We exposed seeds to varied magnetic field strengths of 5 mT, 10 mT, 30 mT and 60 mT for 3h, 4,5h up to 6h and then incubated them for 24h. The number of geminating seeds was recorded and exposed to SPSS computer package, where a significance test based on ANOVA was done. Further analysis involved comparing varied field types, field strengths, and exposure periods. Descriptive data such as grouped median, variance, mean, number of cases, range and skewness were considered.

RESULTS AND DISCUSSION

Table 3 shows the ANOVA results for the effect of exposure period, field strength and field type on germination of bean seads exposed to electromagnetic fields at 95% confidence level. In this case the F value for exposure period is 111.774. This value is calculated as shown below:

$$F=\frac{\text{variance between groups}}{\text{variance expected due to chance (error)}}=\frac{57.153}{0.51133}=111.77$$

If the sample means are clustered closely together (i.e., small differences), the variance will be small, if the means are spread out (i.e., large differences), the variances will be larger. Other F-values are 60.693 and 68.744 for strength of field and type of field respectively. Our significance level is far less than 0.05 therefore we concluded that exposure period, strength of fields and type of field influence on percent germination of beans is not by chance, but due to exposure to static electromagnetic fields. The degree of freedom (df) implies the number of groups less one. The groups are: three types of field (South Pole, North Pole and Helmholtz field); three exposure periods (3h, 4.5h and 6h); four strengths of field (5 mT, 10 mT, 30 mT and 60 mT) and the Control. Each group is either exposed to magnetic field or not. This makes up twenty-two groups. The degree of freedom (df) is calculated by taking the sum of all groups less one (i.e. $\mathrm{df} = \mathrm{N} - 1 \Rightarrow 22 - 1 = 21$). Other studies have shown that the influence of the stationary magnetic field on the seeds increased the germination of non-standard seeds and improved their quality [7, 9, 11, 12, 22, 23]. Table 3 shows a strong relationship between the exposure periods to a magnetic field, varied strength of static electromagnetic fields and types of field and beans percentage germination.

Table 3

ANOVA results for the effect of exposure period, field strength and field type on germination of bean seeds exposed to electromagnetic fields at 95% confidence level

		Sum of Squares	df	Mean Square	F
Exposure period	Between groups	1200.221	21	57.153	111.774
	Within groups	938.288	1835	0.511	
Strength of field	Between groups	38172686.519	21	1817746.977	60.693
	Within groups	54958041.667	1835	29949.886	
Type of Field	Between groups	1010.580	21	48.123	68.744
	Within groups	1284.550	1835	0.700	

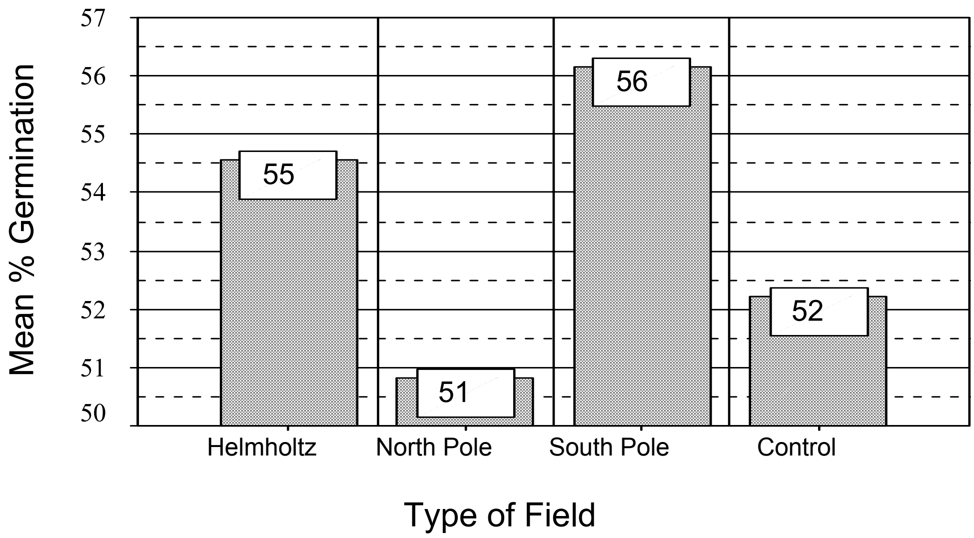

Fig. 3a. Mean percent germination of bean seeds as a function of the type of field.

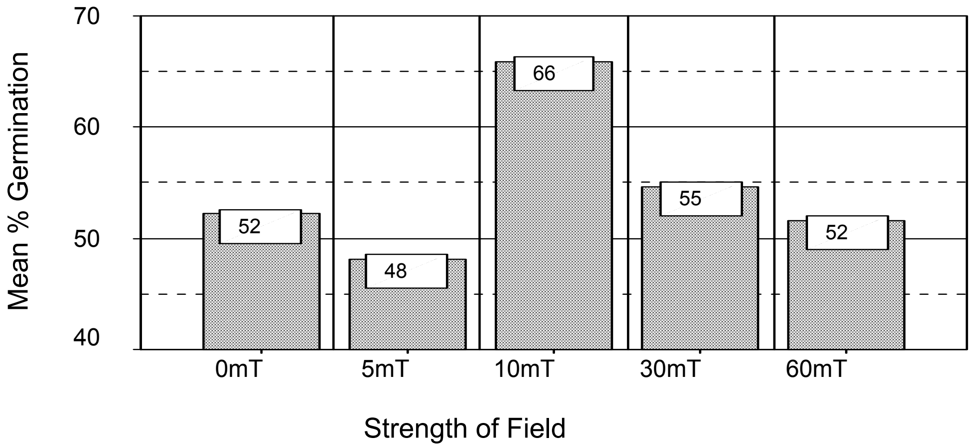

Fig. 3b. Mean percent germination of bean seeds as a function of the strength of field.

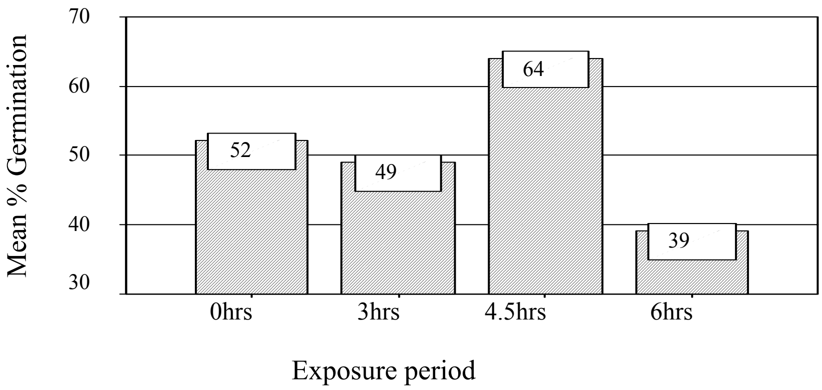

Fig. 3c. Mean percent germination of bean seeds as a function of the exposure period.

The highest percent germination is achieved by South Pole field (Fig. 3a), at field strength of 10 mT (Fig. 3b), exposed for 4.5 h (Fig. 3c) in comparison to 52% of the control. North Pole field (Fig. 3a), at field strength of 5 mT (Fig. 3b), applied for 6 h (Fig. 3c) inhibits bean seed germination when incubated for 24 h.

TYPES OF FIELD

Table 4 shows the descriptive statistics showing percent germination in relation to the type of field. The mean of percentage-geminated seeds compared to the grouped median shows that the mean is slightly lower than the grouped median. This makes the distribution of data to be slightly asymmetric as shown by the small (less than one) negative skewness. Apart from the North Pole field, the range of germination for control and the other fields (Helmholtz and South Pole field) is

70%. Exposure of germinating beans to South Pole stimulates a wider range of germinating characteristics than the non-exposed as evidenced by a much higher variance in Table 4. South Pole achieving the highest percent germination as shown in Table 5 also evidences this. Exposure of bean seeds to the North Pole and the Helmholtz fields inhibits the development of varied germination characteristics as shown in Table 4. The mean percent germination shows that South Pole and Helmholtz fields stimulate a faster germination, whereas the North Pole field inhibits seed germination (Table 4). The number of individual data considered for analysis (N) for each field type is shown in Table 4.

Table 4

Descriptive data showing percent germination in relation to the type of field

Field	Grouped Median	Variance	Mean	N	Range	Skewness
Helmholtz	59.97	306.734	54.56	473	70	–0.895
North Pole	53.49	252.060	50.82	474	67	–0.724
South Pole	57.44	374.246	56.16	468	70	–0.747
Control	57.37	328.117	52.22	443	70	–0.568

At 3 h and 6 h exposure every type of field inhibited seed germination. At 4.5 h exposure, every type of field makes beans seeds to germinate more than the control with South Pole field achieving the highest percent germination followed by Helmholtz field and finally by North Pole field (Table 5).

Table 5

Percent germination of bean seeds as a function of the type of field for constant magnetic field treatment and different exposure periods

Exposure period	Type of Field			
(h)	Helmholtz	North Pole	South Pole	Control
0	–	–	–	52
3	47	49	51	–
4.5	64	60	68	–
6	43	37	37	–

When fields of 5 mT, 10 mT, 30 mT and 60 mT are considered, Table 6 shows that apart from 10 mT, the other field strengths regardless of the type of field are within positive or negative 10% of the control (0 mT). Seeds exposed to 10 mT achieve the highest percent germination in all field types; with South Pole field achieving the highest percent germination of 72%, followed by Helmholtz field at 68%, and finally 59% of the North Pole field compared to 52% of the control. Similar results were noted when rice (*Oryza sativa* L.) seeds were magnetically treated by the static and dynamic method [7].

Table 6

Percent germination of bean seeds as a function of the strength of the field for constant magnetic field treatment and different types of field

Type of field	Field strength (mT)				
	0	5	10	30	60
Helmholtz	–	49	67	54	54
North Pole	–	45	59	52	51
South Pole	–	50	72	59	50
Control	52	–	–	–	–

EXPOSURE PERIOD

From Table 7, it is noted that regardless of exposure period, grouped median is greater than mean percent germination. This has resulted in negative skewness, with non-exposed bean seeds and those exposed for 6 h having less than one, whereas 3 h and 4.5 h exposure have more than one. The range and variance of the control are higher than those corresponding to beans exposed to magnetic fields. Faster seed germination is experienced when seeds are exposed for 4.5 h (64%), whereas 3 h and 6 h exposures inhibit bean seed germination across all fields (Fig. 3c, Table 5 and Table 7). The number of individual data considered for analysis (N) for each exposure period is shown in Table 7.

Table 7

Descriptive data showing percent germination in relation to the exposure period

Exposure (h)	Grouped median	Variance	Mean	N	Range	Skewness
0	57.37	328.117	52.22	443	70	–0.568
3	53.67	139.465	49.04	417	57	–1.285
4.5	68.88	238.935	63.97	671	60	–1.818
6	39.89	242.489	39.17	327	57	–0.409

Table 8 shows how field strength relates to exposure period. Field strength of 5 mT stimulates slightly a faster germination than control at 3 h, while it inhibits bean seed germination at 4.5 h and a slightly faster germination at 6 h exposure periods. This is contrary to 10 mT and 30 mT field strengths, which encourages faster seed germination at 4.5 h and inhibits germination at 3 h and 6 h exposure periods. Field strength of 60 mT stimulates faster bean seed germination at 3 h and 4.5 h exposure periods whereas it inhibits germination at 6h exposure period. This increase in germination has been noted in onion and rice, wheat, rice and maize seeds exposed to weak electromagnetic fields at different exposure periods [1, 4, 5, 7].

Table 8

Percent germination of bean seeds as a function of the strength of the field for constant magnetic field treatment and different exposure periods

Exposure period (h)	Field strength (mT)				
	0	5	10	30	60
0	52	–	–	–	–
3	–	54	3	29	56
4.5	–	22	72	73	58
6	–	53	6	24	32

STRENGTH OF FIELD

Table 9 shows percent germination in relation to the strength of the field. The mean of percentage-geminated seeds compared to the grouped median is lower. This makes the distribution of data to be negatively skewed. Field strength of 5 mT, 10 mT and 60 mT experience a negative asymmetry greater than the control. Exposure of germinating beans to field strengths of 10 mT and 30 mT stimulates germination (Table 9). Field strengths of 5 mT and 60 mT inhibit germination (Table 9). The mean percent germination shows that field strength of 10 mT achieves optimum germination, followed by 30 mT. The field strengths of 10 mT and 30 mT stimulate germination the fastest, while field strengths of 5 mT and 60 mT inhibit germination (Table 6 and Table 9). The number of individual data considered for analysis (N) for each set field strength is shown in Table 9.

Table 9

Descriptive data showing percent germination in relation to the strength of the field

Strength (mT)	Grouped Median	Variance	Mean	N	Range	Skewness
0	57.37	328.117	52.22	443	70	–0.568
5	50.44	165.301	48.15	381	43	–1.257
10	69.78	358.672	65.94	234	74	–2.739
30	70.00	536.156	54.64	370	67	–0.432
60	55.08	122.742	51.61	430	43	–1.446

The same results were found while using wheat, barley and oat seeds [6], and while using tobacco seeds (*Nicotiana tabacum* L.) [2], though they applied different field strengths from the ones in this experiment. Field strength of 5 mT inhibits germination regardless of the type of field (Table 6). Seeds are inhibited to germinate when exposed to 60 mT, North and South Pole fields.

Varied exposure periods influence germination of beans at a certain field strength (Table 8). Bean seeds exposed for 3 h to 5 mT and 60 mT nearly germinate as control. At field strength of 10 mT and 30 mT, bean seeds exposed for 3 h and 6 h are inhibited to germinate. Exposed for 4.5 h, germination of beans is inhibited at 5 mT, whereas it is stimulated at 10 mT, 30 mT and 60 mT exposure. Similar observation though exposed chronically was observed when rice (*Oryza sativa L.*) seeds exposed to 150 mT magnetic fields persistently increased both the rate and percentage of germination relative to control. Significant differences were also obtained for seeds exposed to a 250 mT magnetic field for 20 min [7]. The optimum percent germination occurs at field strength of 30 mT at exposure period of 4.5 h achieving about 73% bean germination compared to 52% of the control (Table 8).

CONCLUSIONS AND RECOMMENDATIONS

In conclusion, maximum seed germination occurred when exposed to South Pole field inducing percent germination of 73% compared to 52% of the control at field strength of 30 mT at exposure period of 4.5 h. The ANOVA significance test ($p < 0.05$) shows that exposure period, strength of fields and type of field influence germination of beans when exposed to static electromagnetic fields incubated for 24 h. Further research need to be done by exposing bean seeds to the found magnetic field strength; within 4.5 h exposure so as to enable seed companies investigate this influence before seed germination. The above findings have met the initial aim of this research which was to investigate whether static magnetic field influences germination of seeds when strength of field and exposure period are treated as parameters, incubated for 24 h.

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