EFFECT OF PULSED MAGNETIC FIELDS TO THE GROWTH RATE OF GREEN SOYBEAN

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Abstract

This research is to investigate and makes preliminary comparison effect of pulse magnetic field to the growth rate of green soybean with sinusoidal wave signal and variety of magnetic field value. A circuit had been designed and developed to generate pulse magnetic field that consist excitation ferrite-core coil, diode, power MOSFET, resistor, function generator as signal generator and power supply. Selection of excitation coil and designed circuit had ability to produce a stable value of magnetic field value and 50 Hz frequency became main critical characteristic. Selected green soybean seeds were exposed to three types of waveforms, which are sinus wave, square wave, sawtooth wave and 50 Hz as frequency value was used for each type of waveforms. In the experiment, the range between 3 milli Gauss until 600 milli Gauss were being used as magnetic value which that involve 400 seeds arranged in a line for each magnetic field values. Values of magnetic field had been determined by the distance between source (excitation ferrite-core coil) and subject (green soybean). 7 day of experiment had done and sample was taken randomly. Experiment being separate into two parts where the first part was the first 3 days in the dark and second part was balance 4 day of experiment under daylight. From results sine wave, 6 magnetic field values at root inhibit germination rate while 6 magnetic field values at hypocotyls part has speed up growth rate. Moreover, growth rate at leaf part also has speed up but only for 70 mG magnetic field. For results sawtooth, only 3 magnetic values show speed up progress on growth rate. While others shows sign of decreasing of germination and growth rate for root and leaf part. Lastly for square wave, all the 6 magnetic field seeds show speed up on germination and growth rate for root, hypocotyls and leaf.

1.0 Introduction

Investigation regarding to effect magnetic field to plant had done by many researchers. Their investigations were covered from variety aspect sides for example in physically such as weight of fruits, length of shoot, length of root, length of leaf, length of hypocotyls and etc. Moreover, they also investigated on the physiology changes in plants such as nutrient element uptake, electroporation, cell volume change due to water uptake and etc [4, 6-10]. Normally most of their experiment used extreme low frequency (ELF), static electromagnetic field and alternating electromagnetic field [4, 6, 11].

In this research, pulsed-generator electromagnetic field had been developed to be simply circuit and it could compatible to use variety of ferrite-core coil. The important thing while making consideration was on limitation of electromagnetic field produces by coil so that specific component will place on the circuit which can stabilize drive current to the coil. Other than that, selected coil can pick-up three types of waveform which are square wave, sawtooth wave and sinusoidal wave.

This research did not complete without selected subject which grow up faster because limitation of time experiment process. Selected subject was green soybean and consideration of genetic, sizes of seed and weight of seed also important that will become main factor for manipulating the result of experiment. Moreover, orientation of green soybean position while been exposed to pulse electromagnetic field also should be considering as design of experiment.

The main purpose of doing this research is to view green soybean growth rate due to the exposure of variety of pulse in electromagnetic field. In this research also include variety of ELF and electromagnetic field value being done to make solid comparisons to the researches

2.0 HARDWARE

This chapter is separated into three main sections: hardware development, experimental procedures and statistical method. This chapter presented the hardware development, the experimental procedures and the statistical analysis used in this research project. In the first subchapter, a research framework was. Next, in the hardware part, the coil and electronic components used to design the drive current circuit were discussed. Preliminary circuit testing before final working circuit in the experiment were elaborated. FEMM simulation was conducted to stimulate and estimate the mapping magnetic field. From this magnetic flux density map, it would have helped to decide on using "U" shape placement. This 'U' shape was decided because of high magnetic flux density at the middle of the magnetic coil and low magnetic flux density at the end of both coil's poles. Seed selection was essential activity because criteria of samples can manipulate results of experiments. Step by step and sampling methods for treated and un-treated samples were described. The experiment procedures were repeated for 6 MF values and 3 types of waveforms. Lastly, the method of data analysis, biostatistical analysis, was elaborated.

2.1 Coil

A coil was used to produce MFs in this research. Previous researchers custom-made their coil. In this experiment, a simple coil that could withstand a 50 Hz and 50% duty cycle waveform and also could withstand a high current was designed, as shown in Figure 3.2. The selected hash choke, 5252-RC, had a total of 250 winding turns. It was manufactured by Bourns company. The coil had a double-layer winding enamel copper wire, with an outer diameter of 0.81 mm and a ferrite core diameter of 11.08 mm, as shown in Figure 3.3.

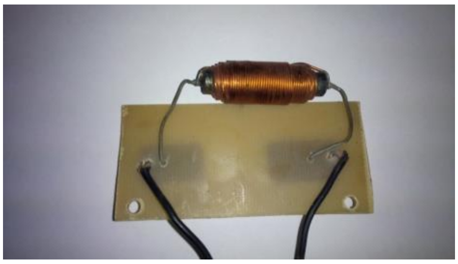

Figure 3.2 Excitation coil

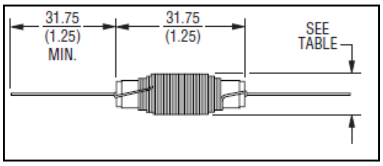

Figure 3.3 Excitation coil dimensions

2.2 Circuit Design

Figure 3.6 shows PWM circuit with a current drive circuit to the coil. An MOSFET was added to give square wave signals in between 0 to 5 V. This circuit could produce MF higher than 2000 mili Gauss, up to 1MHz frequency. After performing circuit testing, setting could be 78 Hz or 50 Hz as both could give a stable square waveform. This circuit could control voltage and current supplies and thus induce current to the coil could be controlled. Ultimately, MF could be controlled.

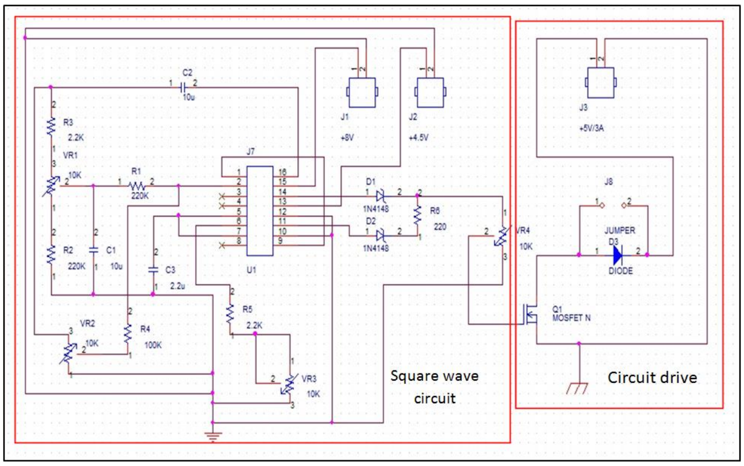

Figure 3.6 Circuit Drive with IC UC3825 and Power MOSFET

The final circuit had a MOSFET component for driving the current. In this research, N channel MOSFET (IRF540N) and diodes (1N5820) were used as the MOSFET could with stand more than 3A while maximum 3A for diode. PWM design in Figure 3.6was not used because it would not be easy to change to other types of waveform. Instead, in this research, a function generator was used to source for pulsed signals. Measurements were taken using a Gauss meter (EMF 1394. The operating voltage was between -5 to +5 V, 10 V peak to peak.

Software ORCAD version 9.2 was used to layout the circuit design. Figure 3.8 shows the current drive circuit. J3 represented the coil, J2 referred to the function generator, Q1 referred to the power MOSFET and J1 represented the voltage source.

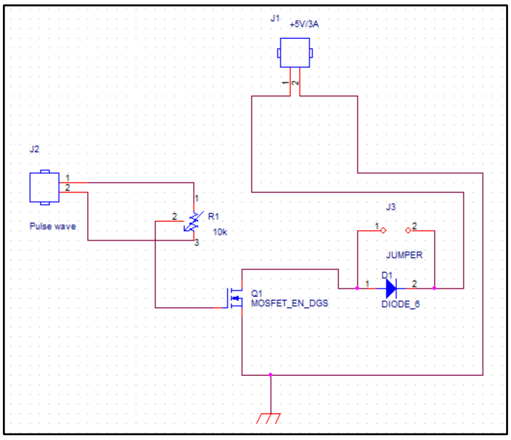

Figure 3.8 Current Drive circuit

3.0 Finite Element Method Magnetic simulation

By using the Finite Element Method Magnetic (FEMM) approach, the MF for the designed coil could have been estimated. The parameters included 250 turns of coil (model 5252-RC) and 1.5A current injection to the coil. MF flux mapping could not be felt or seen by naked eye, but it could be simulated. Figure 3.10 shows the simulation output to predict and view the magnetic flux in air before reaching sample under tested. The simulation was essential to be used to determine the placement of the sample that exposed to the MF. As can be seen from Figure 3.10, the high intensity of MF was found at the middle of magnet, the signals were degraded gradually till the both end of magnetic pole. Green denoted the lowest MF density. It showed MF distribution at the middle of the coil. Magnetic flux density was highest at the middle and the lowest at the both end side of the coil It was suggested that the seeds under tested should be placed in "U" shape, farer from the centre of the coil and nearer to the both coil ends, so that they were equally projected with the magnetic flux.

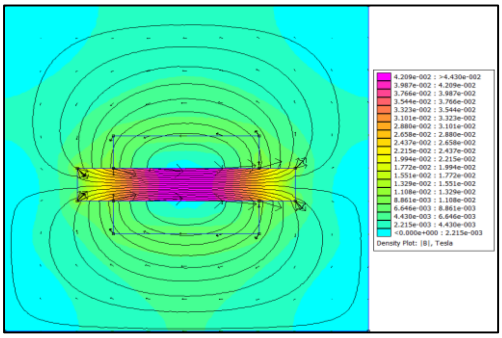

Figure 3.10 Magnetic Flux Density mapping

3.1 Experimental Procedures

3.1.1 Seed Selection

In this research, green soybean seeds were the samples under tested for MF exposure. The green soybean (MKS1) seed was recommended by MARDI because it is commonly used in industry and suitable due to fast results. Seeds were selected by their size as well as weight to ensure consistency of experiments. Each the samples was 65 ±1 mg and 5 ± 1 mm, weight and length respectively. Samples were easy to find in these measurements.

3.1.2 Arrangement of subject experiment

Figures 3.11 and 3.12 show the "U" shape placement of the samples under tested.

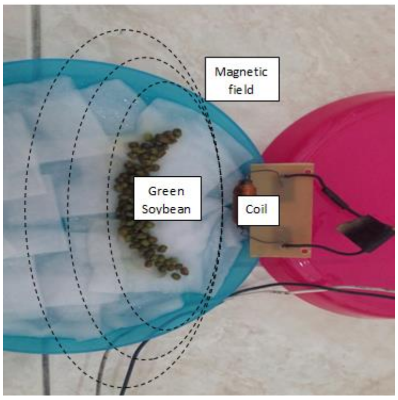

Figure 3.11 Top view

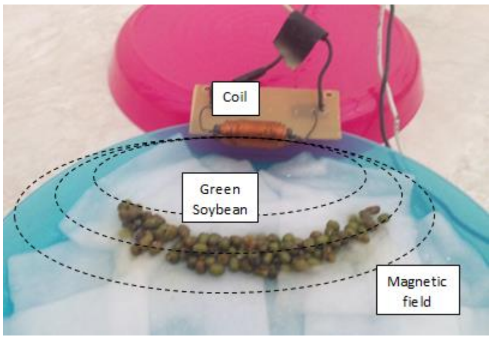

Figure 3.12 Front view

3.1.3 Experiment

The experiments used pulse MF because MF can penetrate deeper into biology cell compare to the EF. MF was measured using a Gauss meter and a ruler. Experiments were performed inside a room. The exposed samples were placed on wet cotton for germination process. Wet cotton were used to prepare moist condition that chemical reaction would have happened when water had get into seed. This chemical reaction was the starting point for germination process. Using a hygrometer, TFA 30-5002, the humidity and the temperature in the surrounding environment were monitored. It was measured constantly at around 89±3% RH of humidity and 27±3 °C of temperature. Watering the seeds was done 3 times, at 8.00 am, 12.00 pm and 6.00 pm every day. Experiments were done in a total of 7 days. On the first 3 days, experiments was performed in dark condition, then on normal day light for the balance 4 days. The treatment was performed for 4 hours each the days.

Figure 3.13 Growth of green soybean from seed

The seeds were exposed to the magnetic field every morning from 8.00 am until 12.00 pm. During the 7 days of the experiment, before the experiment started, a Gauss meter was used to check whether any changes to the MF values. Figure 3.13 shows the growth stages of green soybean. A random of 400 exposed samples were measured and measurements were done by thread and ruler like figure 3.14.

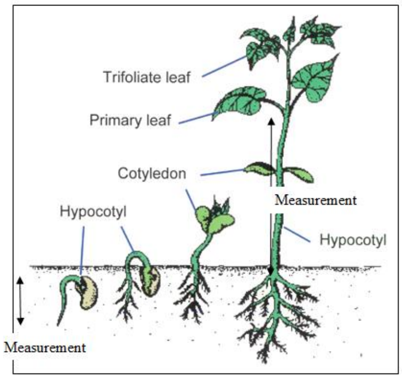

Figure 3.14 Measurement taken during experiment

Measurements were taken on preliminary stage where first root came out from the samples, then measurements were continually for the same 400 samples from first until third day of experiments. These first three days indicated a germination process. Then, for the next 4 days, the samples were put under day light condition. These four days of experiment were the growth process where hypocotyls and leaf came out from seed. Measurements for hypocotyls and leaf were taken on each the days. This procedure was repeated for 3 types of waveform (sinus, square and sawtooth) and 6 values of MF (600 mG, 100 mG, 70 mG, 20 mG, 8 mG and 3 mG). To have controlled samples, 400 seeds that did not exposed to any MF were measured at the same room and the same duration of the exposed samples under treatment. The controlled samples were also had 3 days of the germination process in dark condition and then 4 days of the growth process in day light condition. Each the samples were done in 7 days because of controlling the height of seed. By controlling the height of green soybean seed, at the same time, it also controlled the value of magnetic field that exposed to hypocotyls and leaf of green soybean plant.

3.2 Biostatistical Analysis

Statistics is the science of learning from data or the science of collecting and analysing data for the purpose of decision making and scientific discovery when there are limited amounts of variable information available. Statistics applied to biological problems is simply called biostatistics. Once the data are collected, they need to be summarised and described in order for informative presentation. These procedures are called descriptive statistics. Then, the data need to be analysed for generalised conclusions; the term for this is inferential statistics. In this research, the biostatistical analysis was performed with Statistical Package of the Social Sciences (SPSS) 18. In the next subsections, two statistically tests that were used to make conclusions from data collected in this research are discussed [54, 55].

First test was student t-test, to compare two sets of data to determine whether there had any significant differences. The two sets of data referred to the exposed samples and the controlled samples. Then, second test was ANOVA (Analysis of variance), to compare two or more sets of data among the exposed samples to determine whether there had any significant differences. The two or more sets of data here referred to the exposed samples to the different values of MF.

3.2.1 Student t-test

In the student t-test, P-value is the probability, that, if the null hypothesis is true, sampling variation will produce an estimation that is further away from the hypothesised value than the expected data. Before doing tests on data, we must decide on a significance level (alpha value): 0.001, 0.01 or 0.05. The significance level is to determine significant differences between two sets of data after calculate t (statistic). In this research, 0.05 was chosen as the alpha value. Sections below, null hypothesis, alternative hypothesis and ANOVA steps to calculate t (statistic) are discussed.

3.2.1.1 **Null Hypothesis**

The null hypothesis, denoted as H_0, is expressed as follows for the t-test comparing two population means, μ_1 and μ_2:

$$H_0: \mu_1 = \mu_2.$$

3.5.1.2 **Alternative Hypothesis**

The alternative hypothesis, denoted as H_1, is expressed as one of the following for the t test comparing two population means, μ_1 and μ_2:

$$H_1: \mu_1 \neq \mu_2 \text{ (two-tailed t test),}$$

$$H_1: \mu_1 < \mu_2 \text{ (one tailed t test),}$$

Or

$$H_1: \mu_1 > \mu_2 \text{ (one-tailed t test).}$$

$$T = \frac{\bar{x} - \bar{y}}{\sqrt{\frac{(n_1 - 1)S_x^2 + (n_2 - 1)S_y^2}{n_1 + n_2 - 2}\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}} \quad (1)$$

T is t statistic value,

$\overline{x}$ is x mean values,

$\overline{y}$ is y mean values,

n_1 is the number of x_i observations, n_2 is the number of y_i observations,
S_x^2 is the sample variance of x_i , S_y^2 is the sample variance of y_i,
x is the sample average for x_i , and y is the sample average for y_i

3.5.2 ANOVA

Analysis of variance (ANOVA) is a method for testing the hypothesis that there is no difference between two or more populations (usually at least three). Calculating an ANOVA means that we want to calculate the F statistic. There are six steps to calculating the F statistic:

1. Calculation of "sum of squares" between groups
2. Calculation of "sum of squares" within groups
3. Determine the degrees of freedom for each
4. Calculation of "mean square between"(MSB) and "mean square within"(MSW)
5. Calculation of the F ratio (or F statistic)
6. Making a decision

Degrees of freedom between (DFB) and the degrees of freedom within (DFW) can be calculated in the following way:
DFB = No. of groups - 1
DFW = Population size - No. of groups

$$MSB = \frac{Sum\ of\ Square\ Between}{Degree\ of\ Freedom} \tag{2}$$

$$MSW = \frac{Sum\ of\ Square\ Within}{Degree\ of\ Freedom} \tag{3}$$

$$F = \frac{MSB}{MSW} \tag{4}$$

4.0 RESULTS

This section discusses the results of hardware and experiment and provides statistical analysis. During the hardware testing, there were a few considerations to be taken into account. When function generator generated the voltage peak to peak (V_{pp}), the waveform showing the frequency and the duty cycle would be displayed on an oscilloscope. Each time before starting an experiment, the function generator must be measured by the oscilloscope to ensure that there was no change in frequency and duty cycle of the V_{pp} waveform. Next, voltage and current supply were set at the function generator according to the investigated value of the MF in each the experiments.

The MF produced by coils can be calculated by using equation (5):

$$B = \frac{\mu_o i N}{2\pi r} \tag{5}$$

B = flux density (Tesla, T)

μ_o = permeability material (Henry per metre, Hm^{-1})

i = current (Ampere, A)

N = number of coil turn (turn, t)

r = radian (metre, m)

4.1 Relationship among frequency, current of coil circuit and MF

This test was performed to check the MF performance in terms of the changes of voltage, current and frequency. Here, sine waves were generated that duty cycle was set to 50 %. Table 4.1 show the comparisons between 78 Hz and 50 Hz, that, the frequencies were applied to the coil. Both the frequencies were chosen because of they are common frequencies that use in normal day life. MF values were measured using a gauss meter at 10 mm distance of the coil. This distance was necessary to have all experiements tested in a constant distance. Tables 4.1 tabulates the results.

Table 4.1: Sine Wave comparison 78 Hz and 50 Hz

Sine Wave					
78 Hz			50 Hz		
Supply to coil circuit		Gauss Meter	Supply to coil circuit		Gauss Meter
Voltage (V_{RMS})	Current (A)	Magnetic Field (mG)	Voltage (V_{RMS})	Current (A)	Magnetic Field (mG)
3.00	0.19	778	3.00	0.20	817
3.50	0.39	1438	3.50	0.41	1516
4.00	0.58	1760	4.00	0.60	1799
4.50	0.79	1954	4.50	0.81	1942
5.00	0.98	2001	5.00	1.00	2040
5.50	1.17	Limit	5.50	1.21	Limit
6.00	1.39	Limit	6.00	1.41	Limit

By increasing the voltage value, the values of current and MF rose. The results also showed that after 1 ampere, the Gauss meter detected a MF value out of limit. the specification of the Gauss meter in used was 20-2000 mili Gauss. Results with “Limit” indication showed that the pulse MF inducing by the coil was higher than 2000 mili Gauss. Sine wave generated in different frequencies supplied different levels of current and voltage and thus resulted with different levels of MF. The lower frequency supplied a higher current. This can be seen from the equation of inductance reactance below:

$$X_L = \omega L \tag{6}$$

$$X_L = 2\pi f L \tag{7}$$

X_L = inductance reactance (ohm, Ω)

ω = angular frequency

L = length (Henry, H)

f = frequency (Hertz, Hz)

From the equation, increasing the coil’s frequency will increase the inductance reactance of the coil. This will affect the current that going through the inductor. From the tabulated data, changing the supplied voltage also changing the current going through the coil. This situation can be clearly seen by plotting a graph, as shown in Figure 4.1, the relationship between the voltages supplied to the coil circuit and the resulted MF values.

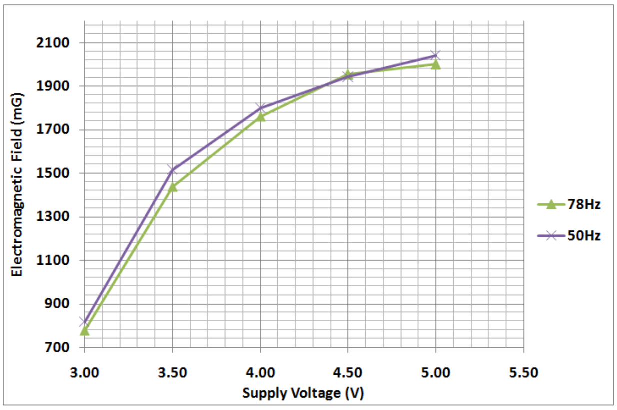

Figure 4.1 Relationship between the voltage supplied to the coil circuit and the magnetic field produced

4.2 Experiment (Biostatistical analysis)

T-test

This t-test was used to compare significant differences between the exposed seeds and the controlled seeds. From the t-test table, there was one significant difference during the experimental period of 7 days. The test was done for 3 parts of the germination and growth of seed: the hypocotyls, roots and leaf. The null hypothesis for this t-test was that the mean for all exposed seeds was equal to those of the control seeds, while the alternative hypothesis was there are significant difference between exposed seeds and control seeds. Below shows the procedures of hypothesis being used:

Hypothesis

Using the significance level, $\alpha = 0.05$.

H_0: $\mu_1 = \mu_c$. (There were no significant differences between samples and controls).

H_1: $\mu_1 \neq \mu_c$. (There were significant differences between samples and controls).

Note: μ_1 = mean sample no 1. This sample was counted until 6 of 6 samples achieved different means. μ_c = mean of the controlled sample.

ANOVA

ANOVA was used to detect different between mean parameters. This meant that there were significant different between exposure seed. Below show the procedures of hypothesis being used:

Hypothesis

Using a significance level, $\alpha = 0.05$.

H_0: There were no significant differences between the exposed seeds.

H_1: There were significant differences between the exposed seeds.

4.4.1 Results of sine wave signal and analysis

Table 4.3 shows the t-test results for root where samples taken from first day until third day of experiment. All the p-values were lower than the alpha value (0.05), except exposed samples to 100 mG MF. At 100 mG MF level, the null hypothesis was rejected. The t-test resulted that there were significant differences between the exposed and controlled samples for all samples except the samples that exposed to 100 mG MF. Besides, means value of 100 mG exposed samples was equal to the control value means, thus, as a result, the p-value for the 100 mG exposed samples was greater than alpha value.

Table 4.3: T-test for root

Magnetic field	Root		
	t	DF	Sign.
600 mG	-9.942	399	0.00
100 mG	0.000	399	1.00
70 mG	-3.760	399	0.00
20 mG	-13.146	399	0.00
8 mG	-5.495	399	0.00
3 mG	-3.998	399	0.00
Note: Ctrl = Control, t = t-statistic, DF = degree of freedom, Sign. = p-value/probability value (2-tailed)			

From Table 4.4, p-value in ANOVA test was lower than alpha value. This shows that null hypothesis being rejected, that, there are significant differences between all exposed samples

.

Table 4.4: ANOVA for root

	Root				
	SS	DF	MS	F.	Sign.
Between Groups	1542.708	5	308.542	19.083	0.000
Within Groups	38706.250	2394	16.168		
Total	40248.958	2399			
Note: SS = Sum of Squares, DF = degree of freedom, MS = Mean Square, F. = F-statistic, Sign. = p-value/probability value (2-tailed)					

Figure 4.5 shows that means of length versus MF. 100 mG scored the highest value of means (6.25 mm) while 600 mG and 20 mG scored the lowest value means (4.00 mm). It can be concluded that different MF values do not speed up the germination rate. For 400 samples each the tested groups, only 100 mG showed significant increase in length. MF values tested with 600 mG, 70 mG, 20 mG, 8 mG or 3 mG showed the germination rates were inhibited.

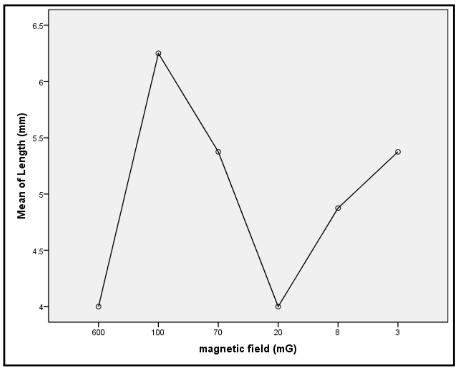

Figure 4.5 Mean Plots for root

Results from table 4.5 shows that all the p-values were lower than alpha value. These meant that all null hypothesis were rejected and alternative hypothesis were accepted. There were significant differences between the exposed and the controlled seeds. Table 4.6 shows ANOVA test, p-value was lower than alpha value. It was concluded that there were significant differences between all exposed sample seeds.

Table 4.5: T-test for Hypocotyls

Magnetic field	Hypocotyls		
	t	DF	Sign.
600 mG	33.477	399	0.000
100 mG	85.061	399	0.000
70 mG	60.772	399	0.000
20 mG	9.392	399	0.000
8 mG	40.518	399	0.000
3 mG	24.352	399	0.000

Note: Ctrl = Control, t = t-statistic, DF = degree of freedom, Sign. = p-value/probability value (2-tailed)

Table 4.6: ANOVA for Hypocotyls

	Hypocotyls				
	SS	DF	MS	F.	Sign.
Between Groups	304496.875	5	60899.375	49.068	0.000
Within Groups	2971268.750	2394	1241.131		
Total	3275765.625	2399			
Note: SS = Sum of Squares, DF = degree of freedom, MS = Mean Square, F. = F-statistic, Sign. = p-value/probability value (2-tailed)					

Figure 4.6 shows mean of length versus MF for hypocotyls. 70 mG was the highest mean (82.50 mm) while the lowest mean was 20 mG (49.13 mm). While second highest was 100 mG (64.38 mm) follow by 8 mG (57.88 mm), 3 mG (53.13 mm) and 600 mG (51.88 mm). There were significant differences on growth rate of the exposed sample. In addition, mean values for all the exposed samples were above the mean in control group (43.25 mm). It was concluded that MF speeded up the growth rate process.

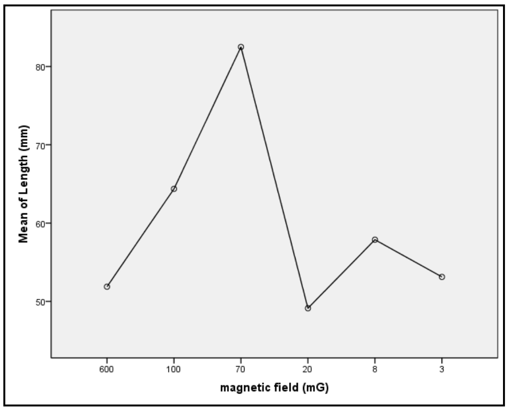

Figure 4.6 Mean Plots for Hypocotyls

Table 4.7 shows t-test for leaf, all the p-values were lower than alpha value. These meant that null hypothesis was rejected and there were significant differences between all the exposed and the controlled samples. Table 4.8 shows ANOVA test, p-value was lower than alpha value therefore null hypothesis was rejected. It can be concluded that there were significant differences between all exposed samples.

Table 4.7: T-test for Leaf

Magnetic field	Leaf		
	t	DF	Sign.

600 mG	-19.274	399	0.000
100 mG	-2.416	399	0.016
70 mG	1.818	399	0.070
20 mG	-7.684	399	0.000
8 mG	-22.484	399	0.000
3 mG	-2.537	399	0.012
Note: Ctrl = Control, t = t-statistic, DF = degree of freedom, Sign. = p-value/probability value (2-tailed)			

Table 4.8: ANOVA for Leaf

	Leaf				
	SS	DF	MS	F.	Sign.
Between Groups	26995.833	5	5399.167	21.764	0.000
Within Groups	593900.000	2394	248.079		
Total	620895.833	2399			
Note: SS = Sum of Squares, DF = degree of freedom, MS = Mean Square, F. = F-statistic, Sign. = p-value/probability value (2-tailed)					

Figure 4.7 shows mean of length versus MF, the plotted graph shows 70 mG was the highest mean value (24.63 mm) while 600 mG was the lowest mean value (15.25 mm). The second highest was 100 mG (23.50 mm) follow by 3 mG (22.88) , 20 mG (18.88 mm) and 8 mG (18.13 mm). Only 70 mG mean value was above control mean value (24.25 mm). It can be concluded that only samples exposed to MF value of 70 mG speeded up the growth of leaf while other MF values inhibited the growth of the leaf.

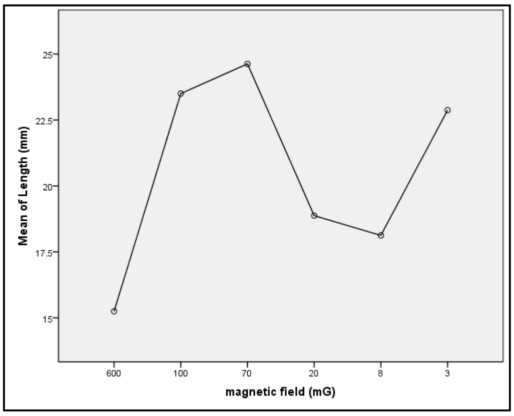

Figure 4.7 Mean Plots for Leaf

4.4.2 Result square wave (Biostatistical analysis)

Table 4.9 shows the t-test results for root where samples were measured for the first three days of experiment. From the table, all the p-values results were below alpha value (0.05) so null hypothesis was rejected. There were significant difference between the exposed and controlled seeds. Table 4.10 tabulated results of ANOVA test, p-value was lower than alpha value thus null hypothesis was rejected. There were significant differences between all exposed sample seeds

Table 4.9: T-test for root

Magnetic field	Root		
	T	DF	Sign.
600 mG	-14.935	399	0.000
100 mG	-14.541	399	0.000
70 mG	-19.411	399	0.000
20 mG	-15.473	399	0.000
8 mG	-18.049	399	0.000
3 mG	-12.915	399	0.000
Note: Ctrl = Control, t = t-statistic, DF = degree of freedom, Sign. = p-value/probability value (2-tailed)			

Figure 4.8 shows mean of length versus MF for root. The highest value was 3 mG with mean value 3.13 mm while the lowest mean value was 70 mG (1.00 mm). Second highest mean value was 600 mG (2.38 mm), followed by 100 mG (2.13 mm), 20 mG (1.75 mm) and 8 mG (1.38 mm). There were significant differences among exposed samples but all mean values of the exposed samples were off the control mean value 6.25 mm. It can be concluded that the treatment was inhibited the germination rate.

Table 4.10: ANOVA for root

	Root				
	SS	DF	MS	F.	Sign.
Between Groups	1145.833	5	229.167	44.423	0.000
Within Groups	12350.000	2394	5.159		
Total	13495.833	2399			
Note: SS = Sum of Squares, DF = degree of freedom, MS = Mean Square, F. = F-statistic, Sign. = p-value/probability value (2-tailed)					

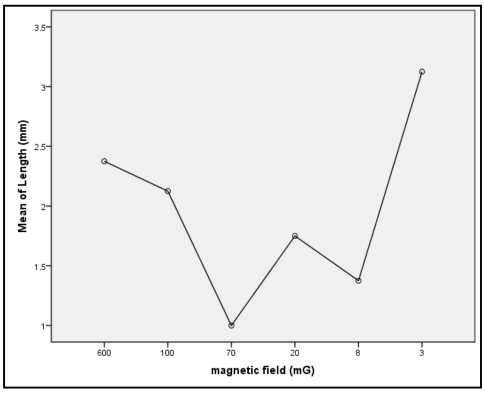

Figure 4.8 Mean Plots for root

Table 4.11 shows results of t-test for hypocotyls, the p-value was lower alpha value (0.05). Null hypothesis was rejected and there were significant difference between the exposed and controlled samples. From Table 4.12, the results of ANOVA test showed that p-value was lower than alpha value and that null hypothesis was rejected. This result indicated that there were significant differences among exposed samples.

Table 4.11: T-test for Hypocotyls

Magnetic field	Hypocotyls		
	t	DF	Sign.
600 mG	-16.032	399	0.000
100 mG	-20.002	399	0.000
70 mG	-22.909	399	0.000
20 mG	-22.152	399	0.000
8 mG	-24.303	399	0.000
3 mG	-18.490	399	0.000
Note: Ctrl = Control, t = t-statistic, DF = degree of freedom, Sign. = p-value/probability value (2-tailed)			

Table 4.12: ANOVA for Hypocotyls

	Hypocotyls				
	SS	DF	MS	F.	Sign.
Between Groups	44634.375	5	8926.875	37.937	0.000
Within Groups	563331.250	2394	235.310		
Total	607965.625	2399			
Note: SS = Sum of Squares, DF = degree of freedom, MS = Mean Square, F. = F-statistic, Sign. = p-value/probability value (2-tailed)					

Figure 4.9 shows plotted graph for mean of length versus MF. The highest mean of length was 600 mG (20.25 mm) while the lowest mean value was 8 mG (8.38 mm). Second

highest length was 3 mG (18.38 mm), followed by 100 mG (13.63 mm), 70 mG (12.75 mm) and 20 mG (9.50 mm). There are significant differences among exposed sample seeds but all values of the mean of length were off the mean control of 43.25 mm. It can be concluded that the growth was inhibited.

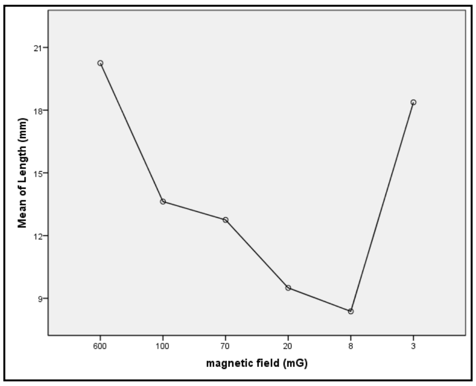

Figure 4.9 Mean Plots for Hypocotyls

Table 4.13 listed the t-test results, all the p-values were below alpha value. Null hypothesis was rejected. There were significant differences between the exposed and the controlled samples. Table 4.14 tabulated the results of ANOVA test, the p-value was below alpha value. Again, null hypothesis was rejected and there were significant differences between the exposed samples of leaves.

Table 4.13: T-test for Leaf

Magnetic field	Leaf		
	T	DF	Sign.
600 mG	-13.967	399	0.000
100 mG	-33.621	399	0.000
70 mG	-34.066	399	0.000
20 mG	-34.066	399	0.000
8 mG	-27.677	399	0.000
3 mG	-16.503	399	0.000
Note: Ctrl = Control, t = t-statistic, DF = degree of freedom, Sign. = p-value/probability value (2-tailed)			

Table 4.14: ANOVA for Leaf

	Leaf				
	SS	DF	MS	F.	Sign.
Between Groups	58670.833	5	11734.167	99.242	0.000
Within Groups	283062.500	2394	118.238		
Total	341733.333	2399			
Note: SS = Sum of Squares, DF = degree of freedom, MS = Mean Square, F. = F-statistic, Sign. = p-value/probability value (2-tailed)					

Figure 4.10 shows that graph mean of length versus MF. From the plotted graph, the highest length value was 600 mG (12.75 mm) while the lowest length value was 70 mG and 20 mG (0.00 mm). Second highest length was 3 mG (9.88 mm), followed by 8 mG (3.88 mm) and 100 mG (1.50 mm). There are significant differences among the exposed leaves but the growth rate was inhibited because all the exposed samples was below control value (24.25 mm).

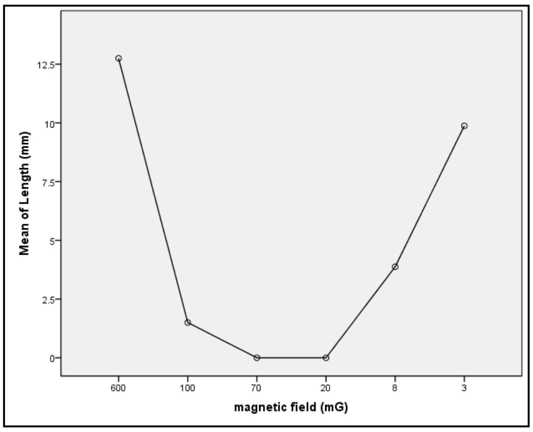

Figure 4.10 Mean Plots for Leaf

4.4.3 Result sawtooth wave (Biostatistical analysis)

Table 4.15 shows all the p-values were below alpha value 0.05. These indicated that there were significant difference between the exposed and controlled samples. Null hypothesis was rejected. Table 4.16 tabulated the results of ANOVA test, p-value was below alpha value. Again, null hypothesis as rejected and there were significant differences among exposed samples.

Table 4.15: T-test for root

Magnetic field	Root		
	T	DF	Sign.
600 mG	-15.788	399	0.000
100 mG	-11.710	399	0.000
70 mG	-13.180	399	0.000
20 mG	-11.177	399	0.000
8 mG	-8.830	399	0.000
3 mG	-11.625	399	0.000
Note: Ctrl = Control, t = t-statistic, DF = degree of freedom, Sign. = p-value/probability value (2-tailed)			

Figure 4.11 shows the plotted graph, that, 8 mG (4.13 mm) was the highest mean value while the lowest mean value was 20 mG (2.00 mm). Second highest value was 3 mG (3.00 mm) followed by 600 mG (2.88 mm), 100 mG (2.63 mm) and 70 mG (2.25 mm). There were

significant difference on all the exposed samples but the germination rate was inhibited because control value mean (6.25 mm) was higher than the exposed samples.

Table 4.16: ANOVA for root

	Root				
	SS	DF	MS	F.	Sign.
Between Groups	1109.375	5	221.875	25.347	0.000
Within Groups	20956.250	2394	8.754		
Total	22065.625	2399			
Note: SS = Sum of Squares, DF = degree of freedom, MS = Mean Square, F. = F-statistic, Sign. = p-value/probability value (2-tailed)					

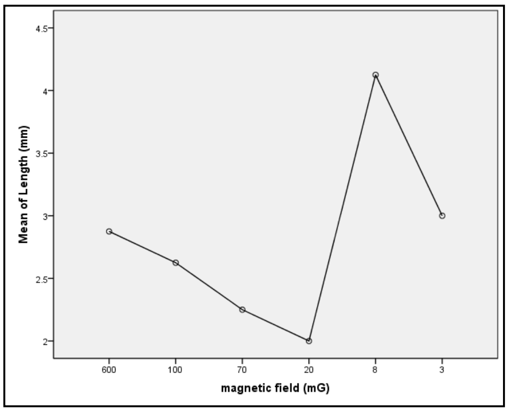

Figure 4.11 Mean Plots for root

Table 4.17 tabulated the p-values of the t-test, all the p-values were lower than the alpha value. Null hypothesis was rejected. There were significant difference between the exposed and controlled samples. From table 4.18, the ANOVA test result showed that the p-value was lower than the alpha value. Null hypothesis was rejected and there were significant differences among the exposed hypocotyls.

Table 4.17: T-test for Hypocotyls

Magnetic field	Hypocotyls		
	t	DF	Sign.
600 mG	-18.558	399	0.000
100 mG	-7.956	399	0.000
70 mG	-13.187	399	0.000
20 mG	17.922	399	0.000
8 mG	6.713	399	0.000
3 mG	7.900	399	0.000
Note: Ctrl = Control, t = t-statistic, DF = degree of freedom, Sign. = p-value/probability value (2-tailed)			

Table 4.18: ANOVA for Hypocotyls

	Hypocotyls				
	SS	DF	MS	F.	Sign.
Between Groups	597837.500	5	119567.500	216.914	0.000
Within Groups	1319625.000	2394	551.222		
Total	1917462.500	2399			
Note: SS = Sum of Squares, DF = degree of freedom, MS = Mean Square, F. = F-statistic, Sign. = p-value/probability value (2-tailed)					

Figure 4.12 shows plotted graph for mean of length versus magnetic field. From the graph, the highest value was 20 mG (59.40) while the lowest value 600 mG (19.18 mm). The second highest value was 3 mG (50.17 mm), followed by 8 mG (49.31 mm), 100 mG (27.84 mm) and 70 mG (20.59 mm). There were significant differences among the exposed hypocotyls but only samples exposed to 20 mG, 8 mG or 3 mG showed speed up growth. Others exposed samples showed inhibited growth rate because of lower value than the control value (43.25 mm).

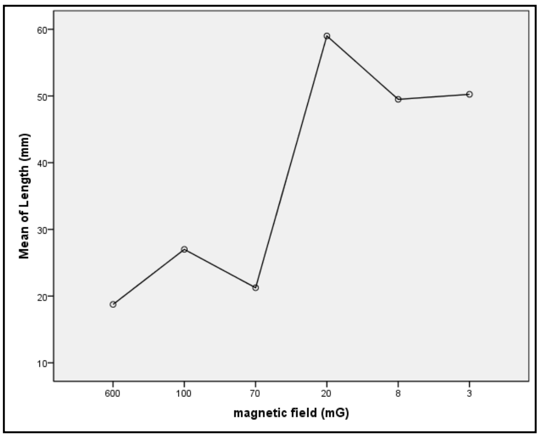

Figure 4.12 Mean Plots for Hypocotyls

Table 4.19 shows the p-values for t-test, all were lower than alpha value. Null hypothesis was rejected and there was significant difference between the exposed and controlled samples. Table 4.20 tabulated the results of ANOVA test. Again, the p-value was lower than alpha value. Null hypothesis was rejected and there were significant differences among the exposed samples.

Table 4.19: T-test for Leaf

Magnetic field	Leaf		
	T	DF	Sign.
600 mG	-29.050	399	0.000
100 mG	-13.727	399	0.000
70 mG	-13.852	399	0.000
20 mG	-10.775	399	0.000
8 mG	-5.033	399	0.000
3 mG	-8.741	399	0.000
Note: Ctrl = Control, t = t-statistic, DF = degree of freedom, Sign. = p-value/probability value (2-tailed)			

Table 4.20: ANOVA for Leaf

	Leaf				
	SS	DF	MS	F.	Sign.
Between Groups	86970.833	5	17394.167	73.014	0.000
Within Groups	570325.000	2394	238.231		
Total	657295.833	2399			
Note: SS = Sum of Squares, DF = degree of freedom, MS = Mean Square, F. = F-statistic, Sign. = p-value/probability value (2-tailed)					

Figure 4.13 shows graph plotted for mean of length versus magnetic field. The highest value length was 3 mG (22.38 mm) while the lowest value was 600 mG (4.88 mm). The second highest mean value was 8 mG (21.25 mm), followed by 20 mG (18.63 mm), 100 mG (12.88 mm) and 70 mG (12.75 mm). There were significant differences among the exposed samples but growth rate was inhibited because the control value (24.25 mm) was higher than the exposed samples.

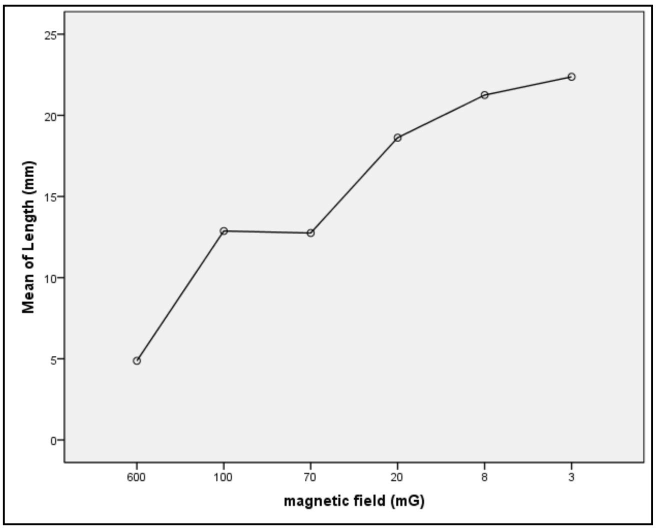

Figure 4.13 Mean Plots for Leaf

5.0 Conclusion

This section presented results of the hardware testing. There was an indication that a slight change of the frequency affected the current generating through the coil and then resulted different electromagnetic field values. The biostatistical analysis was then be elaborated. Below subsections provide summaries for the biostatistical analysis.

	Sine
Root	• T-test: significant differences except the samples exposed to 100 mG. • ANOVA: significant differences among all the exposed samples. • Only the samples exposed to 100 mG showed germination rate equal to the controlled samples. The other 5 exposed samples were inhibited germination rate.
Hypocotyls	• T-test: significant differences between the exposed and controlled samples. • ANOVA: significant differences among all the exposed samples. • All means of the exposed samples were above control mean, the exposed samples showed a speed up growth rate.
Leaf	• T-test: significant differences between the exposed and controlled samples. • ANOVA: significant differences among all the exposed samples Only samples exposed to 70 mG showed a speed up growth rate while other 5 samples were inhibited growth rate.

Conclusion can be made from the above summary that t-test and ANOVA for root, hypocotyls and leaf showed significant differences. For root part, only 100 mG germination rate was equal to control. The growth rate for hypocotyls was speed up for the exposed samples. More than that, only samples of leaf exposed to 70 mG showed speed up growth. From these findings, sine wave only affected hypocotyls and leaves that speeded up the growth rate in MF values of 600 mG, 100 mG, 70 mG, 20 mG, 8mG and 3 mG, except for leaf part (70 mG).

	Square
Root	• T-test show significant differences between exposed samples seed and control. • ANOVA also show significant differences between all exposed sample seeds. • All exposed samples mean was below 6.25 mm (control mean). This show inhibit germination rate.
Hypocotyls	• T-test show significant differences between exposed samples seed and control. • ANOVA also show significant differences between all exposed samples hypocotyls. • All exposed samples mean was below control mean 43.25 mm that show inhibited growth rate.
Leaf	• T-test show significant differences between exposed samples seed and control. • ANOVA also show significant differences between all exposed sample leaves. • All exposed samples mean was below 24.25 mm (control mean) that show inhibited growth rate.

Conclusion can be made from results of square wave experiments, that, t-test and ANOVA for root, hypocotyls and leaf showed significant differences. All exposed samples were inhibited of the germination and growth rates. These were shown that all MF values for the square wave experiments could have used to slow down the germination and growth rates in the green soybean because the germination and growth rates were lower than control value.

	Sawtooth
Root	• T-test show significant differences between exposed samples seed and control. • ANOVA also show significant differences between all exposed sample seeds. • All exposed samples mean was below 6.25 mm (control mean). This show inhibit germination rate.
Hypocotyls	• T-test show significant differences between exposed samples seed and control. • ANOVA also show significant differences between all exposed samples hypocotyls.

	• Only exposed samples seed to 20 mG, 8 mG and 3 mG show speed up growth rate but other 3 exposed samples seed was inhibited growth rate.
Leaf	• T-test show significant differences between exposed samples seed and control. • ANOVA also show significant differences between all exposed sample leaves. • All exposed samples mean was below 24.25 mm (control mean) that show inhibited growth rate.

From summary table of sawtooth results, t-test and ANOVA showed significant differences for root, hypocotyls and leaf part. For root and leaf part, there were inhibited germination and growth rates during all the 7 days of experiments. This situation was opposite to hypocotyls part where three the exposed samples showed speed up growth rate while the other three exposed samples were inhibited.

It was also found that almost all the levels of MFs in sine waves inhibited the germination rate except those samples exposed to 100 mG. This result also can be found from previous literature review, Hsin and his team concluded that the germination was inhibited specifically for a frequency of 50 Hz [51]. However, there were other researchers get different result, as an example, Angle's team using onion seeds as the exposed samples showed that a sine wave exposure of 160 mT, 60 Hz for 15 or 20 minute enhanced the germination and growth rates [4]. Hsin's group also concluded that 20 Hz or 60 Hz enhanced the germination of mung bean. However, as frequencies of 10 Hz, 30 Hz and 40 Hz inhibited the germination rate. [51].

For square wave, there were significant differences in the experiments, that, an exposure to the MF inhibited the germination and growth rates for root, hypocotyls and leaf. For all the tested 50 Hz MF levels (600 mG, 100 mG, 70 mG, 8 mG and 3 mG), the square wave MF slowed down the germination and growth rates.

The data analysis for sawtooth wave showed that there were significant differences on results of t-test and ANOVA. For root and leaf, all the exposed samples inhibited the germination and growth rates had inhibited. However, for hypocotyls, the samples exposed to 20 mG, 8 mG and 3 mG speeded up growth rate while the samples exposed to 600 mG, 100 mG and 70 mG showed inhibited trend. This result indicated that sawtooth wave could have had frequencies to speed up or inhibited the germination and growth rates.

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