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Study Effect of a Static Magnetic Field and Microwave Irradiation on Wheat Seed Germination Using Different Curves Fitting Models

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Abstract

In this study, seeds of wheat (Triticum aestivum L.) have been exposing to microwave radiation (MW) for 0 (MW0) (as control), 10 (MW1), and 20 seconds (MW2), followed by exposure to a static magnetic field (SMF) of 125 mT for 0 (MG0) (as control), 1 (MG1) and 3hours (MG2). Whole seed treatments have sown in Petri dishes for 3 replicates each contained 30 seeds. Between different treatments, two mathematical models (Logistic and Gompertz functions) have used for comparative analyses of cumulative germination curves over time. The results were showing the highest value associated with the germination percentage through a magnetically treated seed at (MG2), with a significant positive effect, which increasing by 10.51 and 37.70 %, as compared to (MG1) and (MG0), respectively. In microwave treatment, results showed a varied impact in seed germination, as treatment MW1, where gave high values compared to the MW0 and MW2 treatments, which increased in 7.33 and 47.32 %, respectively. While the lowest value had found in exposure doses MW2 with decreased by way of 37.28 % compared with MW0. Also, there were significant effects of interaction treatments, where MW0×MG2 and MW1×MG2 gave the highest germination percentage compared with other treatments. Among the varied seed treatments, the Logistic function proved the most suitable for describing cumulative germination, because it provided an in-depth fit with the

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knowledge, thus making it somewhat easy to suit. Also, the Gompertz model provides either a smaller fit or else a similar fit. Based on the results obtained from the SMF and MW radiation treatments to stimulate wheat seeds, increasing the time of MW radiation give a negative effect, which can be modified by magnetic field stimulation of wheat seed germination. Therefore, the magnetic field might act used as a non-damaging promoter for the germination of wheat seeds.

Key words: static magnetic field, microwave radiation, germination percentage, mathematical models, Wheat.

1 Introduction

The use of physical treatment procedures is considered one of the most effective methods for improving seed germination and improves plant growth, and this is due to its less harmful environmental effects. The seed germination may be stimulated by many physical methods, for example, heat treatments, ionizing fallout, laser irradiation, ultrasonic, magnetic field, and electromagnetic waves, particularly ultraviolet and microwave radiation. And a specific magnetic field and microwave radiation are the foremost important in pre-sowing seed treatments [1]. It has well known that the MW radiation is part of the electromagnetic spectrum, with frequencies ranging from 300 MHz to 1 GHz with wavelengths varying from 1 m to 1 mm. In the agriculture sector, a short exposure of microwaves has been used successfully as a positive effect on accelerating seed germination [2, 5].While the long exposure usually was resulted in a seed death [6].

A magnetic field (MF) has usually found in a static or alternating mode, where static magnetic field (SMF) originally derives either from a static magnet as a magnetic medium or from the electromagnets fed by direct current. Whereas, the alternating magnetic fields are a time-varying electromagnetic that comes from alternating current movement. The magnetically treated seed germination depends on its magnitude and its nature, static or alternating. In general, SMF effects operation of plants and germination has depended on the magnetic exposure dose (the output of the magnetic field flux density and the exposure time). Several studies have suggested SMF's effect on seed germination as wheat [7]; sorghum [8]; soybean [9]; Chickpea [10]; Lentil [11]; sunflower [12]; Maize [13, 14] and barley seeds [15]. Seed germination is regarded as the first stage of plant growth beginning with water absorption and has commonly, described as the percentage of seeds forming a radical through the seed coat when exposed to suitable environmental conditions [16]. The small amount of data on germination kinetics has given by a reported germination percentage. Moreover, the fitting curve techniques have used to analyze the germination curves by mathematical models, where have been given the most foremost information. Many mathematical models have used for analyzing and describing seed cumulative germination curves, such as functions of Logistic [17, 18];Generalized logistic [19]; Gompertz [20, 21]; Weibull [22, 23], and Richards [24, 25].Additionally, several authors studied the mathematical expressions of cumulative seed germination through the analysis of germination kinetics after prior physical treatment of seeds.The use of the Gompertz model to fit the germination curve of durum wheat seeds after prior alternating magnetic fields have suggested by Muszynski et al. [21].Other authors studied the kinetic seed germination of sunflower magnetically treated by the logistic equation model [26]. The Gompertz curve has used for investigation the effect of laser irradiation on the germination of radish seeds [20].

While other authors have studied the expansion of barley plants exposing to U.V. irradiation, by equations of different mathematical models [27]. There are few studies about combination seed treatments (magnetic field and microwave radiation) compared with studies separate use treatment. This research goal two main objects; one is to study the influences of static magnetic field and microwave radiation on wheat seed germination. And the other aim is to choose the fitting model (Logistic or Gompertz function) suited to cumulative barley seed germination curves under the influence of these factors.

2 Material and Methods

Seeds of wheat (Triticum aestivum L.) cultivars selected for uniform size and shape were firstly soaked for 1 hour (h) in distilled water to enhance the absorption of the energy of the microwave and magnetic field. And then they dried the soaked seeds under the fan. Following that, seeds have been exposed to microwave radiation for 0 seconds as (control, MW0), 10s (MW1) and 20s (MW2). The microwave radiation treatments have administered using an 800W microwave oven at 2450 MHz radiation. The maximum density of irradiation had estimated at 32kW/m3. The estimation had obtained by dividing the output power of the device (800 W) to the working volume having dimensions 0.349 (width) ×0.315 (depth) ×0.227 (height) m3 consistent with the supplier's data used as a microwave oven source.After the microwave treatments, every set of microwave treatment was exposed separately to the static magnetic field (SMF) of 125 mT for 0h (control, MG0), 1h (MG1), and 3h (MG2).The magnetic field determined by gaussmeter produced by Nv.Ltd, India, unit type Nv621. After the combinations of microwave and magnetic exposition treatments, three replicates of 30 seeds each with 90 seeds in each treatment placed in sterilized Petri dishes under laboratory conditions, 100mm in diameter, containing a paper towel moistened with distilled water.

The germinating seed observed after 36h of the beginning of the experiment. A total number of seeds germinated had counted every 12 hours and germination percentage calculated, until the tenth days (after 228 h) when no further germination occurred for three successive counts. The seed was taken into consideration germinated, when the radical it was at least 2 mm.

The percentage of germination (G %) represents the total number of seedlings at the end of the test after ten days, calculated as follows:
G %=(Number of germination seed) / (Total number of seeds planted) ×100

The Logistic and Gompertz models were used for analyses cumulative germination curves over time of wheat seeds under the impact of a magnetic field and microwave radiation and a combination of both these factors. Also, comparisons between the two models have performed. The functions of Gompertz and Logistic have given in the following equations (1) and (2), respectively.

Gompertz model $y = c\exp[-b * \exp(-a * t)]$ (1)

Logistic model $y = c * [1 + b * \exp(-a * t)]^{-1}$ (2)

Where: Y is the cumulative seed germination percentage at time t, t is growing time in hours after sowing, c is the asymptotic value of y (t), which represents the maximum cumulative percentage of germinated seeds, b is the constant, and a is the Relative growth rate. The time of obtaining the curve inflection point of Gompertz and Logistic curve is $T_{inf}= \ln b/a$, also the maximal rate of germination for point of inflection (G_{inf}) of Gompertz and Logistic curves at which growth have been reached to 0.368 c and 1/2 c, respectively. Based on the mean square error (MSE), a sum of square error (SSE), and the determination coefficient (r^2) between the Gompertz and Logistic models, the best-fitting growth curve has done. Also, the statistical analyzes used in the experimental analysis using the SPSS 20 program, according to a completely randomized design, with three replications, each Petri dish represents one replicate. All tests were carried out in the department of agricultural machinery and equipment, in the laboratory of physics, Agriculture College, University of Basrah.

2.1 Derivation of Inflection Point

Inflection point for Gompertz, $\frac{dy}{dx}$ and $\frac{d^2y}{dx^2}$ are given respectively by

Gompertz equation $y = c\exp[-b * \exp(-a * t)]$

The first differentiating $y = c\exp[-b * \exp(-a * t)]$

$$\frac{dy}{dx} = c * \exp[-b * \exp(-a * t)] * ba * \exp - at$$

$$\frac{dy}{dx} = y\, ba * \exp - at$$

It is apparent that the slope is always positive for finite values of t, and approaches zero for infinite values of t.

The second differentiating

$$\frac{d^2y}{dx^2} = -ba^2y * \exp(-at) + ba * \exp(-at) * bay * \exp(-at)$$

The inflection point for Gomportz is given by $\frac{d^2y}{dx^2} = 0$

$$-ba^2y * \exp(-at) = -ba * \exp(-at) * bay * \exp(-at)$$

$$1 = \mathrm{b} * \exp(-at)$$

We see that there will be a point of inflection when T_{inf}= lnb/a

From Eq. 1 the ordinate at the point of inflection is y= c /e = 0.368 c

Inflection point for Logistic, $\frac{dy}{dx}$ and $\frac{d^2y}{dx^2}$ are given respectively by

The first differentiating $\mathrm{y} = \mathrm{c} * [1 + \mathrm{b} * \exp(-\mathrm{a} * \mathrm{t})]^{-1}$

$$\frac{dy}{dx} = abc * \exp(-at) * [1 + \mathrm{b} * \exp(-\mathrm{a} * \mathrm{t})]^{-2}$$

The second differentiating

$$\frac{d^2y}{dx^2} = -a^2bc * \exp(-at) * [1 + \mathrm{b} * \exp(-\mathrm{a} * \mathrm{t})]^{-2} + 2a^2b^2c * \exp(-at) * [1 + \mathrm{b} * \exp(-\mathrm{a} * \mathrm{t})]^{-3} * \exp(-at)$$

The inflection point for Logistic is given by $\frac{d^2y}{dx^2} = 0$

$$a^2bc * \exp(-at) * [1 + \mathrm{b} * \exp(-\mathrm{a} * \mathrm{t})]^{-2} = 2a^2b^2c * \exp(-at) * [1 + \mathrm{b} * \exp(-\mathrm{a} * \mathrm{t})]^{-3} * \exp(-at)$$

$$1 = 2b * \exp(-at) * [1 + \mathrm{b} * \exp(-\mathrm{a} * \mathrm{t})]^{-1}$$

$$1 = 2b * [\exp(at) + \mathrm{b}]^{-1} \Rightarrow 2b = \exp(at) + b \quad \Rightarrow b = \exp(at)$$

We see that there will be a point of inflection when T_{inf}= lnb/a

From Eq. 2, the ordinate at the point of inflection is y= 1/2 c

3 Results and Discussion

Table 1 represents the different percentages of wheat seeds finally germinated. After the tenth-day wheat seeds germinated, all together in Petri dishes, however, at first sight, we could observe a significant difference. Most seeds have germinated in MG0 treatment, but the germination percentage after 228 hours was a maximum of 70.73 %. At the time of the magnetic treatment for 1hour (MG1) and 3hours (MG2), the germination percentage was measured 88.13 and 97.40 %, respectively for 228 hours after sowing. The wheat seed germination percentage is increasing by 24.60 and 37.70 % at a dose rate of MG1 and MG2 compared to the control MG0, respectively.

These results may be parallel to the authors of the previous study who found that an increase in the percentage of germination as a positive response to different periods exposure from a static magnetic field in sorghum [8]; wheat [28, 29], and barley [15].

Table 1: Effect of different exposure times treatments of magnetic field and microwave radiation, and their interactions on the final germination percentage of wheat seeds

Microwave radiation exposure time	**SMF exposure time**			
	MG0	MG1	MG2	Mean
MW0	84.40	90.00	100.00	91.47
MW1	95.60	98.90	100.00	98.17
MW2	32.20	75.50	92.20	66.63
Mean	70.73	88.13	97.40	

L.S.D0.05 (MW=8.80), L.S.D0.05 (MG=8.80), L.S.D0.05 (MW×MG= 15.25). L.S.D0.05=Least significant difference in probability 5%; N.S=Non-significance.

The mechanism of magnetically treated seeds on seed germination had suggested by some researchers, including various possible hypotheses. And these hypotheses may be linked to the activities of certain enzymes and protein formation in magnetically exposed seeds leading to the increased germination and growth of seedlings [30, 31] [9]. In contrast, the magnetic field affects the ability of the cellular tissue to retain water and magnetic energy within the cell. And thus leading to make a biological change in the organism, which can be lead to quick the germinating seeds [26] [11].

Seed treatment with microwave radiation presented a significant effect on wheat seed germination (Table 1). The highest seed germination value of 98.17 % was recorded in MW1 treatment, while a significant reduction was shown within the MW2 treatment of 66.63 %. The increase in the microwave seed exposure level to MW2 showed a significant negative effect on seed germination. A shorter exposure time (10s) showed a higher stimulating effect than the longer one (the 20s). These results are in line with the authors [3], where the authors found that the best germination percentage appeared when exposing the seeds of Buckwheat for 10s to microwave radiation. Similar results have been reported for bean [4] and pepper seeds [2].While, the longer exposure time of MW radiation treatment of lentil seeds showed had an inhibitory effect on plant development [5]. Similar results for corn seeds have reported by other authors [32].While the results of some research have shown indicated that the positive and negative impacts of microwave on germination of wheat seed cultivars [33-34].The commercially acceptable seed germination threshold for wheat 85%.

We have found here that the microwave treatment can improve germination percentage to an extent without reducing the seed quality below the commercial threshold if the microwave input has held to certain levels.
It is well known that microwave radiation has been a positive effect on some plants in accelerating seed germination and has been a negative effect on the others, counting on microwave power energy and exposure period time [3, 6]. The microwave radiation is often broadly classified induces to thermal and non-thermal effects in the biological system of plant seeds whose depends mainly on power. The low power microwave treatment for a short time produces a non-thermal effect. The mechanism of action responsible for the positive effect of pre-treatment of seed with microwave radiation may behave referred to the changes in the inner energy of the seeds.Which also leads to activating various enzymes involved in seed germination [6, 35] and increasing the synthesis of certain biological components in the seeds [3]. Besides, an increase in protein content has found in wheat seedling when the seeds pretreated with microwave radiation [6].Also, the same author found the microwave treated seeds had a positive effect on seed germination due to the increases in enzyme catalase and superoxide dismutase (SOD) activity. Thermal heating of seeds by MW energy, in general, is well known for enhancing seed germination. But a further increase in the exposure time and power level leads to increasing the rate and extent of physical damage and thus leads to hard negative results [36].Also, another effect of MW on water molecules inside the seed plant. The vibration of water molecule dipoles induced by microwave radiation gives a thermal effect, which, according to van Hoff's rule and Arrhenius, the law affects reaction rate in biological processes. An increase in the rate of biochemical changes, maybe results in accelerated or intensified production of auxins and glutathione, which considered for a growth activator during a germination process [37].

The interactions between the two factors, magnetic field and microwave, electric field treatment of wheat seeds, for germination percentage was significant generally. Data presented in Table 1 showed that increasing microwave radiation exerted a negative effect on seed germination percentage. The negative effect of increasing microwave radiation on germination percentage has increased with decreasing magnetic field exposure time. The MW0×MG2 and MW1× MG2 interaction treatments gave the highest germination percentage of 100% compared with MW2× MG0 and MW2× MG1 interaction treatments, which it gave 32.45% and 75.50 %, respectively. The combined effects of magnetic field MG2 with MW2 microwave indicates that the data obtained from the combined treatment resulted in a high reduction of microwave negative impacts on the wheat seed germination.The experimental cumulative germination curves represent the mean values of nine data counted every 12 hours. The germinating seed began to emerge after 36h of beginning sowing. The MG2, MW1, MW0× MG2 and MG2×MW1 treatments were superior compared with other treatments (Figure 1, 2 and 3 respectively). During the magnetic field exposure treatments, MG1 and MG2, the final germination percentage reached 88.13 and 97.40%, respectively, as soon as in hour 228 of the germination process (Fig 1). While, in the microwave exposure treatments MW1 and MW2, the final germination percentage reached 98.17 and 66.63%, respectively, as soon as in hour 228 of the germination process (Fig 2). These best results might be an agreement with the results of several studies authors of various crop seeds exposing to different exposure times of MFs [7, 8 and 15] and MWs radiation [6][4]. Also, in the combination of the magnetic field and microwave exposure treatments MW0× MG2 and MG2×MW1, the final germination percentage reached 100% as soon as in hour 180 (MW0× MG2) and 192 (MW1× MG2) of the germination process (Fig 3).

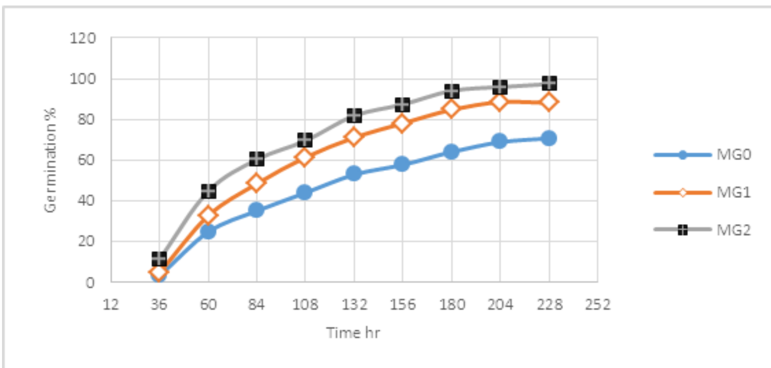

Fig 1: Mean values of germination percentage of wheat seeds as a function of the germination time for various exposure times of magnetic treatment. Exposure times: 1h (MG0), 2h (MG1), and 3h (MG2), MG0 as control.

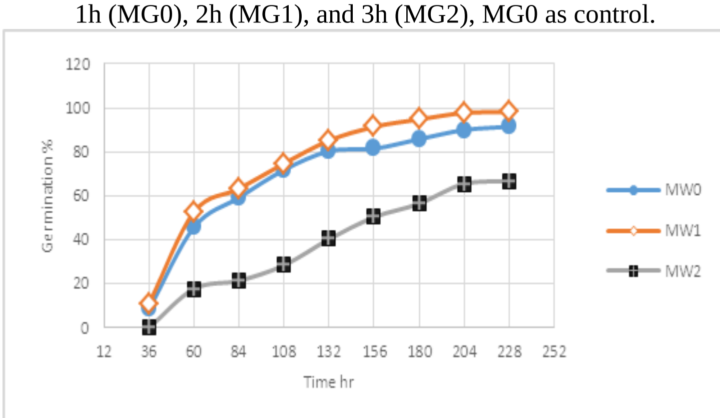

Fig 2: Mean values of germination percentage of wheat seeds as a function of the germination time for various exposure times of microwave treatment. Exposure times: 0s (MW0), 10s (MW1) and 20s (MW2), (MW0) as control.

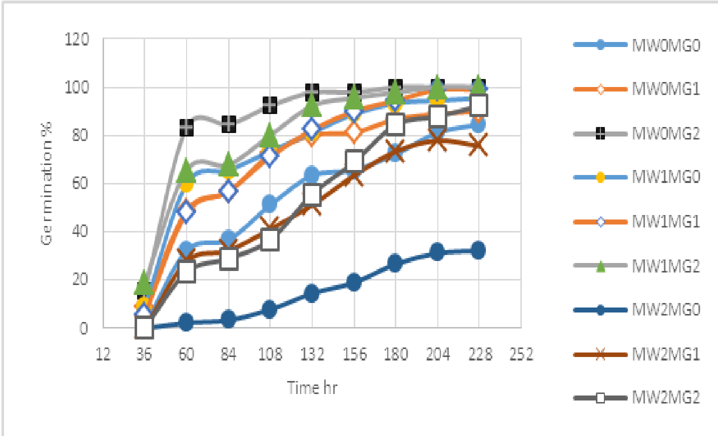

Fig 3: Mean values of germination percentage of wheat seeds as a function of the germination time, for various exposure times of a combination, of a magnetic field and microwave exposure treatments. Exposure times: 0h (MG0), 1h (MG1) and 3h (MG2), (MG0) as control, and 0s (MW0), 10s (MW1) and 20s (MW2), (MW0) as control.

Figures 4, 5, and 6, respectively, represent the impact of the magnetic field, microwave radiation, and both interaction on cumulative seed germination. The germination results obtained from the plotting of Logistic and Gompertz curves based on equations. 1 and 2, respectively. The open symbols in curve figures reflected the values obtained from the experimental observation measurements while the solid symbols collected from the experimental observation calculation. There are few studies about the mathematical expressions of cumulative seed germination through the analysis of germination kinetics after prior physical treatment of seeds. However, there are some authors studied the kinetic seed germination of various crops by different mathematical models. For example, the studied wheat and sunflower seeds magnetization effects by the Gompertz model [21, 26], respectively, studied radish seeds laser irradiated effects by Gompertz models [20], and studied barley seeds UV irradiated effects by several mathematical models [27].

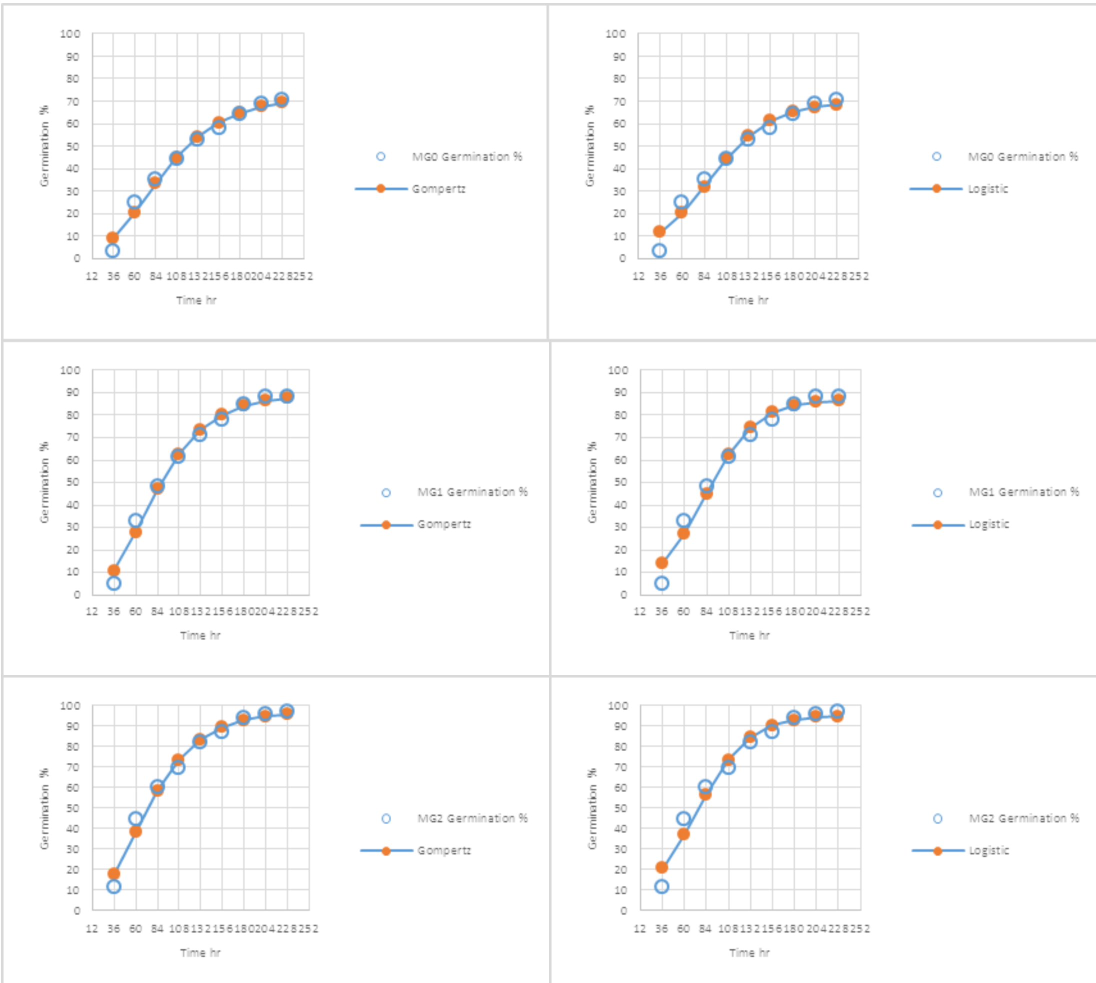

Fig 4: The experimental germination curves of wheat seeds as the function of the germination time for various times of magnetic field exposure, open symbols (o), and model curves, solid symbols(●). Gompertz and Logistic equations were fit to the mean values of 3 replications of 30 seeds each per treatment. Exposure times: 1h (MG0), 2h (MG1), and 3h (MG2), MG0 as control.

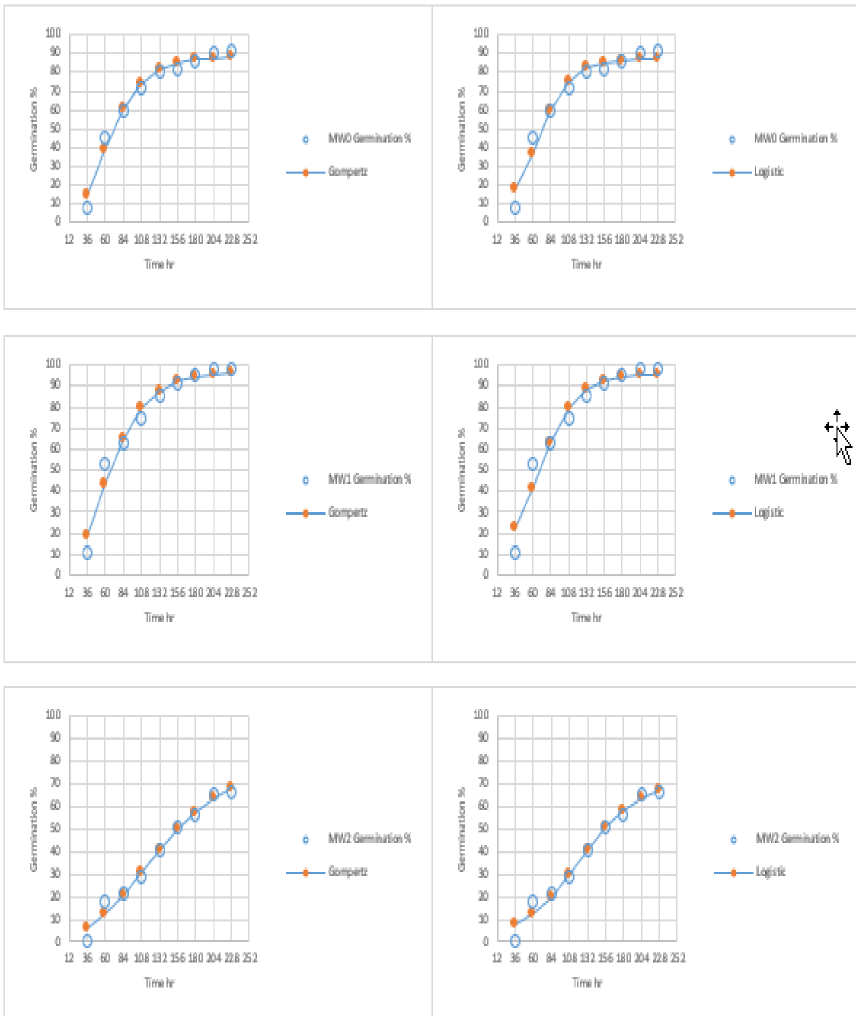

Fig 5: The experimental germination curves of wheat seeds as the function of the germination time for various times of microwave radiation exposure, open symbols (o), and model curves, solid symbols (●). Gompertz and Logistic equations were fit to the mean values of 3 replications of 30 seeds each per treatment. Exposure times: 0s (MW0), 10s (MW1) and 20s (MW2), (MW0) as control.

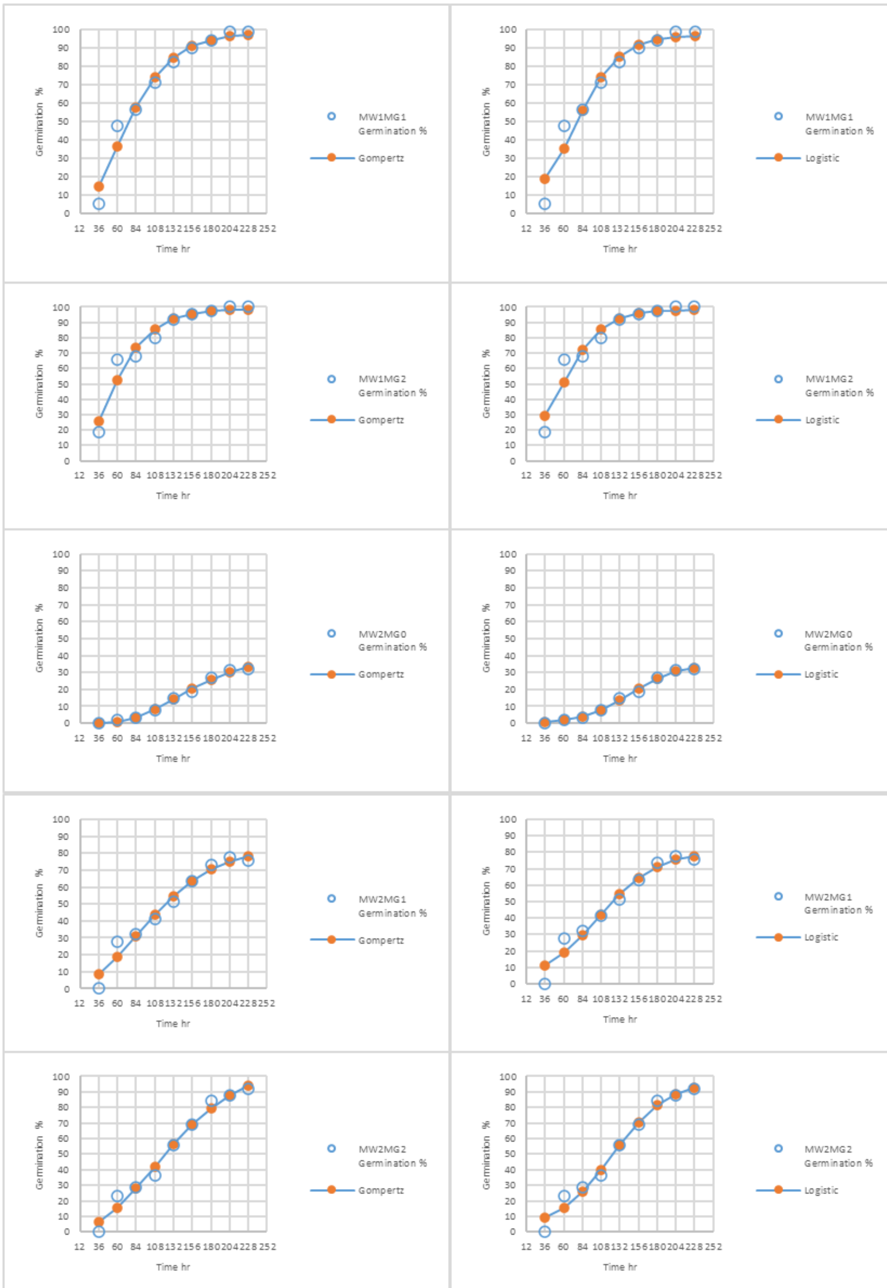

Fig 6: The experimental germination curves of wheat seeds as the function of the germination time for various times of magnetic field and microwave radiation combination exposure, open symbols (o), and model curves, solid symbols (●). Gompertz and Logistic equations were fit to the mean values of 3 replications of 30 seeds each per treatment.

To determine the most effective fitting growth curve, mathematical techniques of Gompertz and Logistic equations had used to fit the experimental data and a good correlation of fit curves with the recorded data had found in some of the treatments recorded. Results from the growth curve fitting of Gompertz and Logistic equations to cumulative germination data in each treatment are summarized in Tables 2 and 3, respectively.

Table 2: Comparison of parameters, r^2 and standard error estimates of Gompertz model for each treatment.

Gompertz model								
Treatment	Parameters				Inflection point		SE	r^2
	r^2 Ob	a (h^{-1})	b	c (%)	T_{inf} (h)	G_{inf} (%)		
MW0	0.80	0.03	5.99	88.04	59.66	32.39	8.69	**0.776**
MW1	0.81	0.03	4.77	96.75	52.07	35.60	9.18	**0.807**
MW2	0.98	0.01	4.49	80.67	150.18	29.68	7.56	**0.991**
MG0	0.93	0.02	4.35	72.09	73.50	26.52	7.27	**0.930**
MG1	0.88	0.03	5.23	89.15	55.27	32.80	9.30	**0.874**
MG2	0.86	0.03	4.27	97.09	48.38	35.72	9.32	**0.858**
MW0× MG0	0.92	0.02	4.27	85.51	48.38	31.46	8.58	**0.941**
MW0× MG1	0.79	0.03	5.58	87.53	57.30	32.211	8.47	**0.778**
MW0× MG2	0.51	0.1	55.62	96.63	40.18	35.55	8.86	**0.411**
MW1× MG0	0.75	0.04	5.92	91.45	44.45	33.65	8.53	**0.731**
MW1× MG1	0.84	0.03	4.85	98.59	52.63	36.28	9.86	**0.856**
MW1× MG2	0.75	0.03	4.11	98.69	47.11	36.31	8.42	**0.764**
MW2× MG0	0.97	0.02	10.81	40.31	119.02	14.83	4.25	**0.970**
MW2× MG1	0.93	0.02	4.25	85.31	72.34	31.39	8.44	**0.968**
MW2× MG2	0.99	0.01	4.83	110.88	157.48	40.80	10.69	**0.990**

a, b, c: model parameters (a: is the Relative growth rate, b: germination rate parameter, c: the asymptotic value for y (t)), SE: standard error of estimation, r^2: coefficient of determination, Ob: observed data.

Table 3: Comparison of parameters, r2 and standard error estimates of Logistic model for each treatment.

Logistic model								
Treatment	Parameters				Inflection point		SE	r^2
	r^2 Ob	a (h^{-1})	b	c (%)	T_{inf} (h)	G_{inf} (%)		
MW0	0.80	0.05	20.15	86.88	60.06	43.44	8.48	**0.770**
MW1	0.81	0.04	13.45	95.64	64.97	47.82	8.97	**0.810**
MW2	0.98	0.03	21.68	71.59	102.54	35.79	7.50	**0.986**
MG0	0.93	0.03	14.63	69.54	141.39	34.77	7.13	**0.931**
MG1	0.88	0.04	18.68	86.98	73.18	43.49	9.12	**0.882**
MG2	0.86	0.03	12.41	95.35	83.95	47.67	9.14	**0.860**
MW0× MG0	0.92	0.03	14.62	82.02	89.41	41.01	8.42	**0.940**
MW0× MG1	0.79	0.04	17.21	86.57	71.13	43.28	8.27	**0.778**
MW0× MG2	0.51	0.14	802.75	96.24	47.77	48.12	8.84	**0.392**
MW1× MG0	0.75	0.05	15.75	90.88	55.13	45.44	8.24	**0.742**

a, b, c: model parameters (a: is the Relative growth rate, b: germination rate parameter, c: the asymptotic value for y (t)), SE: standard error of estimation, r2: coefficient of determination, Ob: observed data.

According to the present results in Tables 2 and 3, the highest value of r2 has recorded with a combination treating seed (MW2×MG0), (MW2×MG1), and (MW2×MG2) for both Gompertz and Logistic equations in comparison to the experimental data set. As well as, the lowest value of the inflection-time parameter had recorded for treating seed (MW0×MG2) for Gompertz and Logistic equations (40.18 and 47.77, respectively). While the highest value of the maximal rate of germination for point of inflection curve had recorded at the treated seed (MW2×MG2) in both Gompertz (40.80) and Logistic (49.14). According to our knowledge, there are no other studies on combination seed treatments (magnetic field and microwave radiation) that have investigated their mathematical expressions of cumulative seed germination through the analysis of germination kinetics after prior physical treatment of seeds. Therefore, it is not possible to compare our results with another study.

4 Conclusions

According to the results obtained from the magnetic field and microwave treated wheat seed, we concluded that applying magnetic field MG2 influence significantly on seed germination. The MW1 treatment confers the highest germination percentage; however, the exposure time is a very important factor, when has exceeded its critical value lead to a negative effect on a germination percentage. Whereas, in the case of a seed exposed to magnetic fields and microwave treatment, the response may be a variable, and therefore, the interaction more varied.

As the MG2×MW0 and MG2×MW1 interactions, the treatments have the highest germination percentage compared with others. This study, therefore, recommends that the use of MW0× MG2 or MW1× MG2 for the enhancement of wheat seed germination. To find the best fit model for observing data, the cumulative germination curves apply. The comparing parameters of the Gompertz and Logistic equations and the observed data germination curves make a proper determining effect on plant germination of the magnetic field and microwave. That parameter of Gompertz and Logistic models varied from treatment to a different one. And this depends on the exposure dose, i.e., (the intensity of the magnetic field and microwave treatments and exposure time).

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