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Magnetic Field Can Improve Germination Potential and Early Seedling Vigor of Cabbage Seeds

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Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript

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ABSTRACT

The effect of magnetic field strengths (5, 10 and 15 mT) for 15, 25 and 35 min, on seed germination, vigor and seedling growth of two cabbage cultivars (Golden Acre and Green Ball) was evaluated through germination test. Higher germination percentage and vigor index was recorded in Golden Acre as compared to Green Ball. Seeds of both cultivars exposed to 5 mT and/or 10 mT exhibited improved uniformity in germination and membrane integrity due to reduction in time taken to 50% germination, mean germination time and electrical conductivity of seed leachates in contrast to control. Cabbage cultivar Golden Acre and Green Ball showed higher vigor and seedling fresh weight in response to magnetic field of 5 and 10 mT, respectively for both 15 and 25 minutes durations. Moreover, efficiency of each magnetic dose declined with increase in exposure time, particularly when seed were exposed to 15 mT. Results revealed significance of magnetic field treatment to improve seed germination (both percentage and uniformity), vigor and seedling growth of cabbage.

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1. INTRODUCTION

Germination, growth, and yield of crops are determined by various factors, the vigor of seeds is probably the first and foremost among those factors. Vigorous seeds ensure rapid and uniform germination, the field emergence is high and uniform, even under adverse environmental conditions. Thus, high quality seeds ensure uniform crop stand and crop maturity, a desirable feature in production of vegetable crops [1]. Seed vigor can be enhanced by several pre-sowing treatments which involve different types of priming [2], seed humidification [3], exposure to electric field, magnetic field (MF), laser radiation and microwave radiation [4,5]. The seed treatments with biophysical methods are comparatively cost effective and can significantly improve the yield without adversely affecting the environment because these treatments are free of toxic residues. They influence the physiological and biochemical processes in the seeds, possibly by increasing the concentration of free radicals as well as activity of enzymes and thereby contribute to improve vigor and crop stand [6].

The useful effects observed on seedlings exposed to magnetic field depend on the specific conditions applied such as time of exposure, magnetic field strength and frequency [7]. The magnetic field is believed to influence the structures of cell membranes and in this way increases their permeability and ion transport through the ion channels, which then affects various metabolic activities [8]. Magnetic treatment has been supposed to improve seed vigor by affecting the biochemical processes that provoke the activity of enzymes, which control the particular stages of seed germination [9]. It also increases protein formation needed to speed up growth processes in seeds of vegetables, fruits and cereals [10]. The magnetically treated seedlings show high rate of shoot and root growth, which ultimately result in improved yield in marigold [3], maize [11], peas[12] and broccoli[13]. But, higher magnetic field strength and long duration of exposure had negative effects [14].

Cabbage (*Brassica oleracea* var. *capitata* L.) is a leafy green winter vegetable crop. It is a rich source of vitamin C (36.6 mg per 100 g of cabbage) and calcium (40 mg per 100 g of cabbage). It also contains appreciable quantity of glutamine that has anti-inflammatory effect. Each 100 g of cabbage provides 103 kJ energy [15]. Previously, it has been observed that seed germination percentage in cabbage vary from variety to variety and within varieties in different seed lots [16]. Therefore, it was hypothesized that seed germination, vigor and early seedling growth of cabbage can be enhanced by using seeds treated with magnetic field as recorded earlier for broccoli [13].

The aim of this study was to examine the germination and early seedling growth of two cabbage cultivars in response to seed stimulation with magnetic field of different strengths and durations.

2. MATERIALS AND METHODS

2.1 Plant Material

The seed of two cultivars of cabbage (*Brassica oleracea* var. *capitata*), namely Golden Acre and Green Ball, which were used and had uniform in size and shape were purchased from a registered (Siddique, Sons) seed corporation. Seed moisture contents were determined before seed treatment using seed moisture meter (GMK-503A, G-Won Hitech Co., Ltd, Korea). The initial moisture content was 7% for Golden Acre and 9% for Green Ball.

2.2 Electro-magnetic Seed Stimulator

Seeds of both cultivars were placed in an Electromagnetic seed stimulator for seed treatment as described by [17]. The electro-magnet consisted of two pairs of cylindrical coils, each formed by 4,000 mm turns of 0.42 mm enameled copper wire (Fig. 1). Each pair of coil was wounded 10 cm apart on an iron bar (dimensions 40 x 3.5 cm). The two bars were placed one above the other, their ends held by metallic supports. The coils were connected in series and fed through a power source of 220 volts containing 50 Hz full wave rectified sinusoidal voltage. When electric current passed through the coils, magnetic field was generated in the air space between the two bars. The field generated in the air space between the two bars measured by magnetic flux meter ELWF (model No. 853396) with the help of probe. The seeds (about 400-500) were placed in Petri dish (9 cm diameter) without any support on the pole of electromagnet. Seeds of two cultivars of cabbage were treated with magnetic field strengths of 5, 10, and 15 mT for 15, 25 and 35 minutes in all possible combinations *viz*., 0mT for 0 min (T_1; untreated seeds), 5 mT for 15 min (T_2), 5 mT for 25 min (T_3), 5 mT for 35 min (T_4), 10 mT for 15 min (T_5), 10 mT for 25 min (T_6), 10 mT for 35 min (T_7), 15 mT for 15 min (T_8),15 mT for 25 min (T_9) and 15 mT for 35 min (T_{10}).

2.3 Germination Test

After seed treatment, germination test was carried out according to International Seed Testing Association [18]. Thirty seeds were placed on double layer of an autoclaved filter paper, soaked with 3 mL of distilled water, in sterilized Petri dishes (9 cm). Petri dishes were placed in an incubator at 23±2ºC. Seeds were considered as germinated when radicle was at least 2 mm in length. The germination data was taken on daily basis up to 7 days. From this germination data, mean germination time [19], time taken to 50% germination (T_{50}) [20] and germination index [21] were also calculated. After 7 days, data was recorded for final seed germination (%), shoot and root length (cm), fresh and dry weight of seedling (mg) and vigor index [22]. Vigour index (VI) was calculated as: VI = Final germination (%) × Total seedling length (cm). Mean germination time (MGT) was calculated according to the following equation:

$$MGT = \frac{\sum Dn}{\sum n}$$

Where n is the number of seeds, which were germinated on day D, and D is the number of days counted from the beginning of germination. The time taken to 50 percent germination [T_{50}] was calculated according to the following formula:

$$T_{50} = t_i + \frac{\left(\frac{N}{2} - n_i\right)(t_j - t_i)}{n_j - n_i}$$

Where N is final number of germinated seeds and n_i, n_j are the cumulative number of seeds germinated by adjacent seed count at times t_i and t_j, respectively.

2.4 Electrical Conductivity Test (µS /cm)

To determine membrane damage, the electrical conductivity (EC) test was conducted according to the recommendations of Association of Official Seed Analysts [22]. Fifty seeds from each treatment were replicated four times and were soaked in 20 mL deionized water for 24 h at

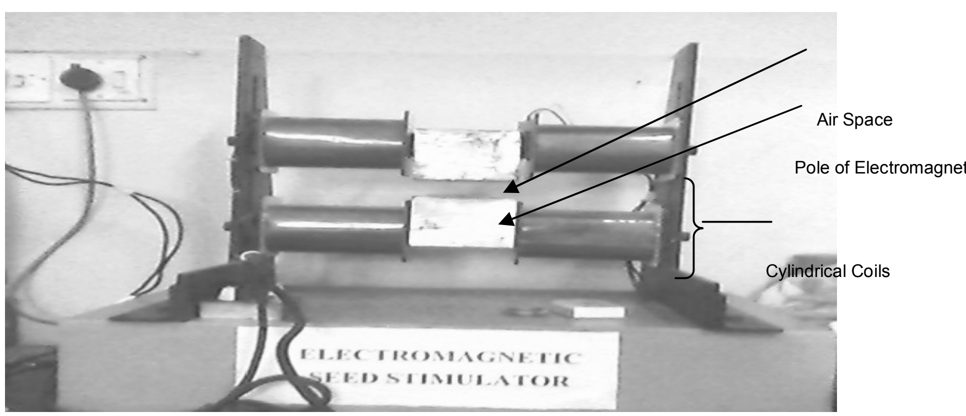

Fig. 1. Electromagnetic seed stimulator

Germination index (GI) was calculated by using the following formulae:

$$\text{GI} = \frac{No. of germinated\ seeds}{Days\ of\ first\ count} + - - - - - - - - - + \frac{No. of germinated\ seeds}{Days\ of\ final\ count}$$

23±2ºC. Electrical conductivity of the leachates was measured with the help of digital conductivity meter (CM-14P, TOA, Electronics Ltd.).

2.5 Statistical Analysis

The experiment was laid out according to Completely Randomized Design with two factor factorial arrangements. There were 10 treatments and each treatment was replicated four times. The data were collected and analyzed using the analysis of variance techniques in the Co-Stat software and significance among treatment means was compared using Duncan's Multiple Range test.

3. RESULTS

Magnetic field treatments of seed significantly changed the germination of two cabbage cultivars (Table 1). Seed vigour of cultivar Golden Acre was better than Green Ball as depicted from results of all the parameters (Table 2). Exposure of seeds to magnetic field of various strengths improved final germination percentage of both cabbage cultivars i.e. for GA (84.72%) and GB (58.18%) as compared to control (untreated seeds); exposure to 10 mT for 35 minutes showed maximum final germination percentage (76.71%) but, was statistically similar to germination in response to several other combinations of magnetic field strength and duration (5mT for 15,25 and 35 min; 10 mT for 15, 25 and 35 min; 15 mT for 15, 25 and 35 min) for both cultivars GA and GB (Table 3). Germination index was high when seeds were exposed to 5mT for 25 or 35 minutes and 10 mT for 35 minutes. Seedling dry weight was maximum while electrical conductivity (EC) of seed leachates was minimum in seeds exposed to 5 or 10 mT for 35 minutes (Table 2).

Analysis of variance revealed interactive effect of cultivar and various magnetic seed treatment were significant for mean germination time (MGT), time taken to 50% germination (T_{50}), vigor index (VI), radicle and plumule length, and fresh weight of seedlings (Table 1).Seeds of both cabbage cultivars exposed to 5 mT magnetic field for 15 and 35 minutes showed significant reduction in MGT and T_{50} values, respectively (Table 3). While, delayed germination as indicated by higher MGT and T_{50}values were recorded in untreated seeds of both cabbage cultivars. Radicle length of cabbage cultivar Golden Acre was increased (47% and 43%) by exposing seeds to 5 mT (for 15 and 25 minutes, respectively) over the control (Table 3). While, exposure of 10 mT for 15 minutes resulted in 34% increase in radicle length of Green Ball seedlings as compared to untreated seeds. Exposure of seeds to 5 mT for 15 and 35 minutes enhanced plumule length by 75% and 25% in cabbage cultivar Golden Acre and Green Ball, respectively, in comparison with control. Fresh weight of Golden Acre seedling was maximum (60.7 mg) in response to 15 mT for 15 minutes while that of Green Ball was highest (42.2 mg) in response to magnetic field treatment of 5 mT for 25 minutes and 10 mT for 25 and 35 minutes. Seedlings grown from untreated seeds of both cultivars had minimum weight (Table 3). Vigour index of Golden Acre was maximum in response to magnetic field of 5 mT strength for 15 and 25 minutes while Green Ball exhibited highest vigor index after exposure to 10 mT for 25 minutes.

The interactive effect of cultivar and magnetic field treatments were non-significant for final germination percentage, germination index, seedling dry weight and electrical conductivity (EC) of seed leachates (Table 1).

To have a more clear insight of the positive or negative effect of various seed magnetic treatments, per cent change in values of different parameters was calculated for mean germination time (MGT), time taken to 50% germination (T_{50}) (Fig. 2), vigour index (VI), radicle and plumule length, and fresh weight of seedlings. The percent change in values of all these parameters depicted positive effects of all magnetic field treatments in cabbage cultivar Green Ball, except plumule length that was 2.3% reduced in response to 15 mT for 35 minutes (Fig. 3). Cabbage cultivar Golden Acre maximum percent increase in radicle and plumule length (Fig. 2) and vigor index (Fig. 4) at 5 mT for 15 minutes while seedling fresh weight at 15 mT for 15 minutes (Fig. 4). Long duration exposure to high magnetic field strength reduced radicle and plumule length, and vigor index in cabbage cultivar Golden Acre in comparison with control.

Table 1. Analysis of variance for seed germination, vigor and seedling parameters of cabbage cultivars in response to magnetic field strengths[a]

Source of variation	Degrees of freedom	FGP	MGT	T_{50}	GI	VI	Plumule length	Radicle length	FW	DW	EC
Cultivar (C)	1	14123.82*	2.13*	4.56*	7815.08*	2643085*	59.85*	18.43*	27011.25*	1980.05*	2814.37*
Seed treatment (T)	9	202.88*	0.09*	0.32*	95.10*	84955.09*	3.34*	1.345*	42822.36*	166.02*	391.05*
C × T	9	111.03[n.s]	0.05*	0.17*	57.78[n.s]	58628.56*	1.73*	1.03*	18133.47*	47.91[n.s]	16.12[n.s]
Error	60	70.28	0.01	0.01	41.53	5389.02	0.11	0.12	6562.08	43.60	8.54
CV		11.73	3.06	6.93	9.9	7.30	7.96	7.65	9.46	26.71	9.0

*FGP= Final Germination Percentage, MGT= Mean Germination Time, T50= Time Taken to 50% Germination, GI= Germination Index, VI= Vigor Index, FW= Fresh Weight, DW= Dry Weight, EC= Electrical Conductivity, a = Mean squares for different parameters, *= significant at 5% probability level, n.s= non-significant at 5% probability level*

Table 2. Individual effect of cultivars and magnetic field strengths on final germination (%), germination index, dry weight and electrical conductivity

Factors/levels	Final germination (%)	Germination index	Dry weight (mg)	Electrical conductivity (µS/cm)
Cultivars (C)				
Golden acre	84.72a	41.00a	2.95a	7.98b
Green ball	58.18b	21.24b	1.94b	19.85a
Magnetic field treatments (MF)				
Control	58.97b	30.71ab	2.75a-c	33.37a
5 mT for 15 min	72.01a	25.92b	2.17cd	12.50bc
5 mT for 25 min	73.73a	35.10a	2.41b-d	9.87c
5 mT for 35 min	72.56a	35.30a	1.93d	10.00c
10 mTfor 15 min	72.01a	29.90ab	2.51a-d	13.43b
10 mT for 25 min	71.10a	33.60a	2.08d	12.50bc
10 mT for 35 min	76.71a	34.10a	3.01a	9.87c
15 mT for 15 min	76.35a	31.20ab	2.81ab	11.50bc
15 mT for 25 min	73.07a	30.00ab	2.38b-d	14.00b
15 mT for 35 min	68.11a	25.90b	2.38b-d	12.12bc
Critical value for comparison	3.74	6.44	6.60	2.92

Table 3. Uniformity of germination, radical and plumule length and weight of seedlings of two cabbage cultivars in response to magnetic field treatments

Cultivars	Magnetic field treatments	MGT (days)	T_{50} (days)	Vigor index	Radicle length (cm)	Plumule length (cm)	Fresh weight (mg)
Golden acre	Control	4.4b-f	1.4de	520.3d	2.8b-d	3.9e-g	25.5ef
	5 mT for 15 min	4.2f	1.3ef	975.5a	4.1a	6.9a	47.5bc
	5 mT for 25 min	4.3ef	1.2f	956.3a	4.2a	6.4a	47.5bc
	5 mT for 35 min	4.3ef	1.2f	800.6b	3.8a	5.2b	29.0d-f
	10 mT for 15 min	4.4 c-f	1.3ef	715.7b	3.2b	5.0bc	36.2c-e
	10 mT for 25 min	4.4b-f	1.3ef	737.3b	3.1bc	6.6a	34.2c-f
	10 mT for 35 min	4.3d-f	1.2f	688.0bc	3.1bc	5.0bc	41.2b-d
	15 mT for 15 min	4.3ef	1.2f	598.6cd	2.3d-f	4.5cd	60.7a
	15 mT for 25 min	4.3b-f	1.2f	561.4d	2.2ef	4.2de	40.2b-d
	15 mT for 35 min	4.3 d-f	1.3ef	397.6d	2.1ef	4.1d-f	52.0ab
Green ball	Control	5.1a	2.7a	241.4f	1.9f	3.1ij	22.5f
	5 mT for 15 min	4.7a	1.7bc	347.0ef	2.1ef	3.8e-h	38.7b-d
	5 mT for 25 min	4.5 a-d	1.7b	325.2ef	2.1ef	3.5g-j	42.2b-d
	5 mT for 35 min	4.6 a-c	1.5cd	337.4ef	2.1ef	3.9e-g	39.0b-d
	10 mT for 15 min	4.6a	1.7bc	376.0e	2.6c-e	3.6f-i	38.7b-d
	10 mT for 25 min	4.6ab	1.6bc	394.6e	2.2ef	3.6f-i	42.2b-d
	10 mT for 35 min	4.5 abcd	1.6bc	335.2ef	2.0ef	3.3h-j	42.2b-d
	15 mT for 15 min	4.6ab	1.7bc	348.2ef	2.1ef	3.3h-j	39.5b-d
	15 mT for 25 min	4.5 a-e	1.6bc	289.3ef	2.0f	3.5g-j	33.0d-f
	15 mT for 35 min	4.6 a-c	1.6bc	321.6ef	2.1ef	3.0j	39.2b-d
Critical value for comparison		0.13	0.10	73.42	0.35	0.34	81.01

MGT = Mean Germination Time; T_{50} = Time taken to 50% germination

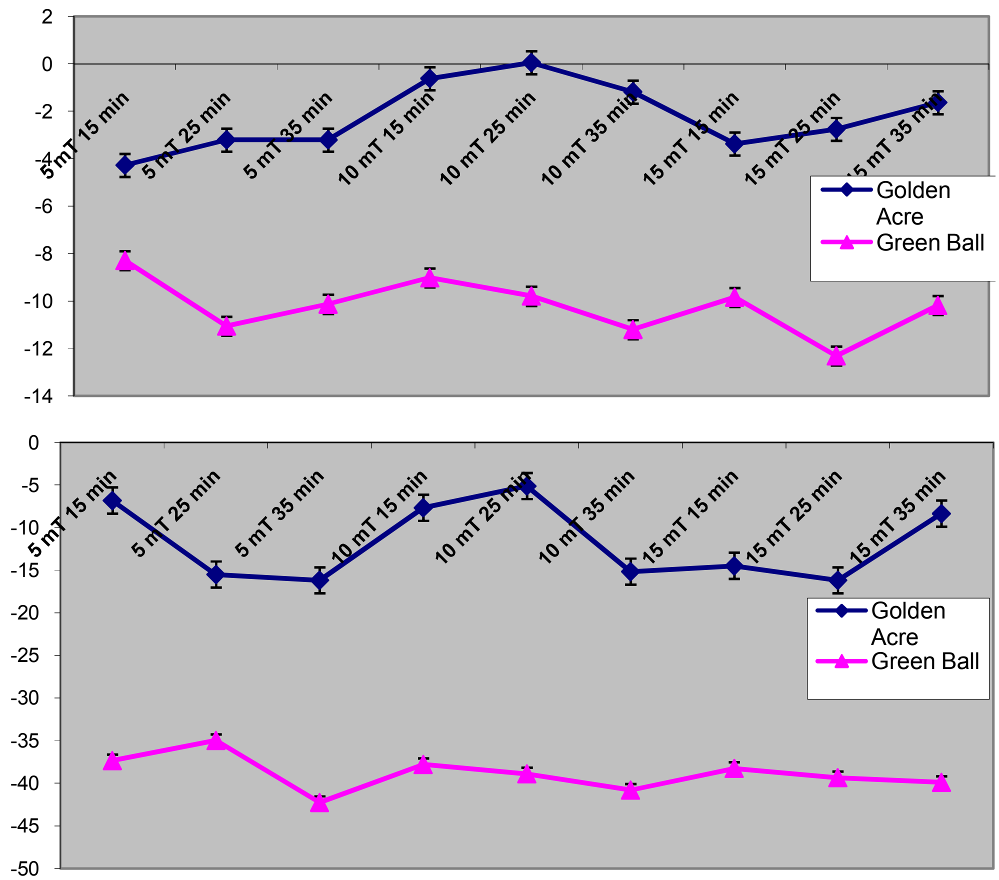

Fig. 2. Percent change (+/-) in mean germination time (upper graph) and time taken to 50% germination (lower graph) of two cabbage cultivars in response to various magnetic field treatments

4. DISCUSSION

Rapid germination increases the chance of seedlings survival and helps the seedlings to grow normally even under adverse soil and environmental conditions [16,1]. Both, magnetic and electromagnetic field treatments of the seeds have been reported to enhance seed germination, seedling growth rate and ultimately the yield. Therefore, the effect of magnetic field of various strength and exposure duration was analyzed on seed germination and vigor indices of two cabbage cultivars. The two cultivars differed in their viability and vigour; cultivar Golden Acre (GA) was superior as compared to cultivar Green Ball (GB). This difference in viability and vigor was helpful in assessing the impact of magnetic seed treatment on the performance of seeds. In general, magnetic seed treatments improved all germination indices final germination percentage (FGP), germination index (GI), time taken to 50% germination (T_{50}) and mean germination time (MGT) of cabbage seeds [23] also reported increased germination percentage of *Satureja bachtiarica* seedlings in response to magnetic seed treatment (1 mT for 2 h). But, magnetic treatments at low strength for various durations and high strength for short duration improved seed germination while, high field strength and longer duration negatively affected seed germination. The improved germination in response to low strength and short duration can be attributed to earlier activation of enzymes in breakdown of stored reserves [12] and thus ensuring the supply of these reserves to the germinating embryo. While longer duration of exposure and high strength might have generated free radicals or otherwise have slowed down the enzymatic activity, which need to be assessed [12] also reported decline in emergence percentage and emergence index of pea seeds treated with strong magnetic field for longer duration [13] also reported decline ingermination of broccoli seed with increase in strength of magnetic field and duration of exposure.

The results also indicate that cabbage cultivar GA, which had high viability and vigor, responded better to low magnetic field strength (5 mT) for various exposure times. While, cabbage cultivar GB showed better germination and vigor, when seeds were treated with 10 mT for 15 to 25 min, although there was not too much difference among various magnetic seed treatments for different parameters [14] observed that maize seeds exposed to magnetic field (125 or 250 mT) for 20 min showed higher germination percentage, shoot length, and seedling fresh weight while T_{50} and MGT was reduced as compared to untreated seeds and seeds treated for longer durations (1 and 24 h). Our results are also congruent with the findings of [24] that 160 mT and 200 mT for 1 min improved shoot length and dry weight and leaf area of 28-day-old tomato seedlings as compared to control seedlings and those exposed to longer durations (10, 15 and 20 min). This increase in length of seedling might be due to enhanced cell division in radicle [3] that emerged earlier from seed coat started root activity earlier than untreated seeds and therefore, resulted in healthy seedlings, in terms of weight, and finally increased vigor (Tables 1 & 2). This improvement in vigor of cabbage seeds could be attributed to stimulation of biochemical processes which affect activities of various metabolic pathways [9] such as protein formation [11] and activation of enzymes [10].

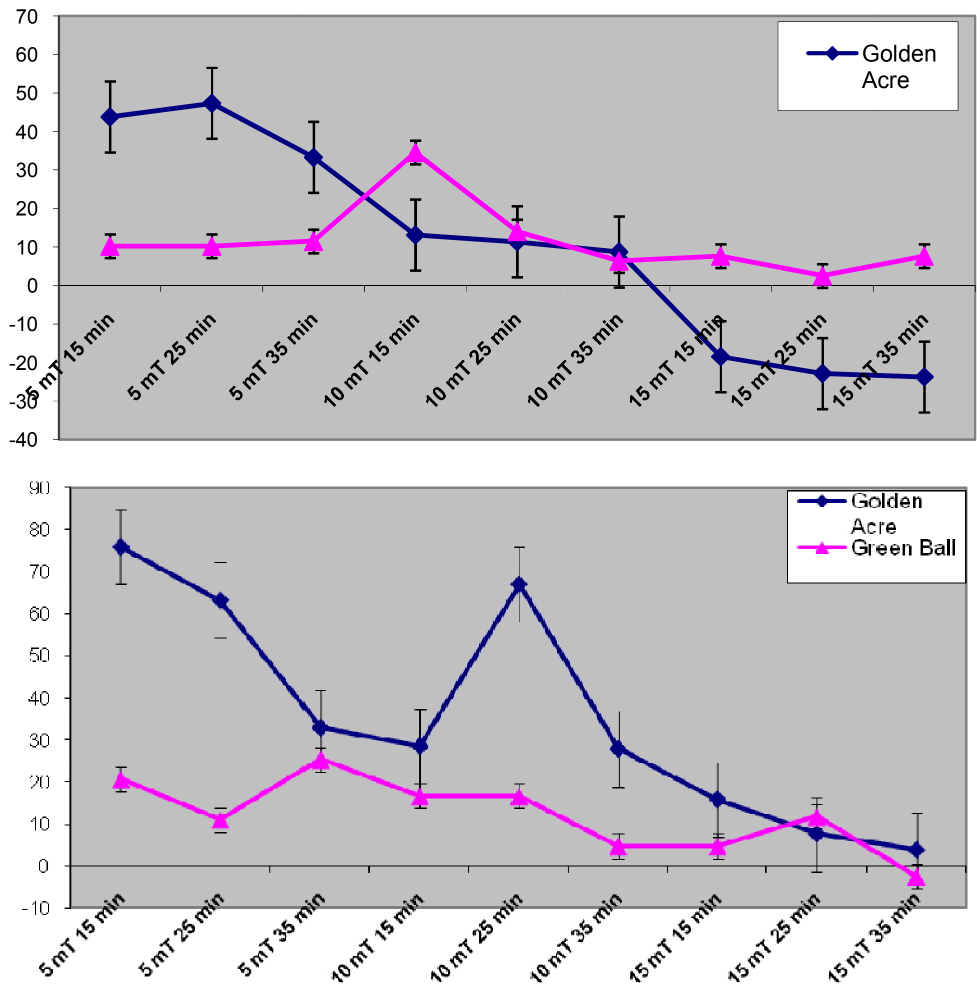

Fig. 3. Percent change (+/-) in radicle (upper graph) and plumule (lower graph) length of two cabbage cultivars in response to various magnetic field treatments

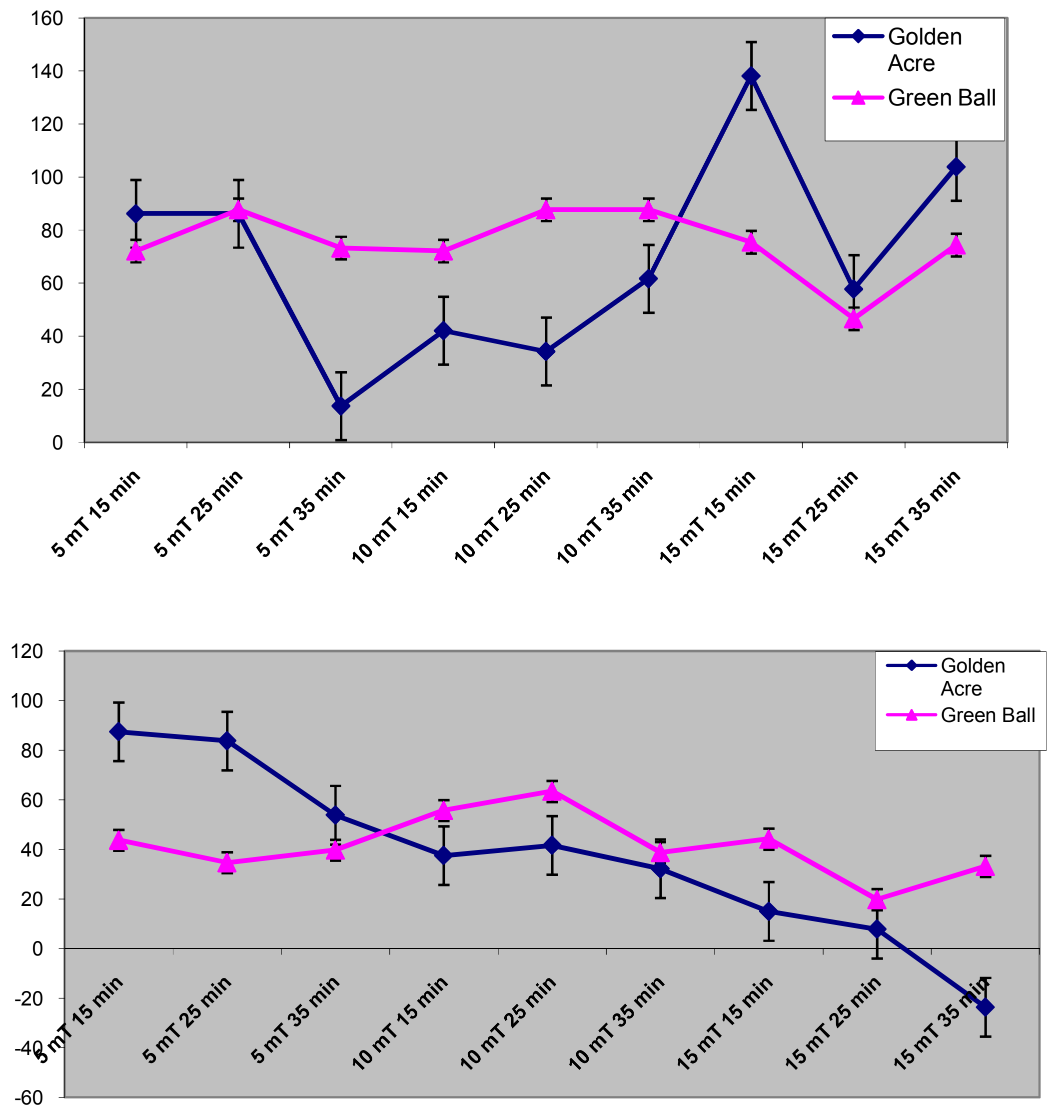

Fig. 4. Percent change (+/-) in seedling fresh weight (upper graph) and vigor index (lower graph) of two cabbage cultivars in response to various magnetic field treatments

Magnetic treatments at low strength (5 and 10 mT), tested in this study, can be helpful in improving crop stand by increasing early and uniform germination (up to 22 to 30% more germination than control) and seedling growth as evidenced by up to 32%, 51%, 86% and 73% increase in radicle length, plumule length, seedling fresh weight and vigor of treated seeds as compared to untreated seeds (Figs. 2, 3 and 4). This increase in germination and seedling growth can help in reducing the quantity of seed to be used as well as can yield earlier and better than the crop raised without seed treatment. Previously, [24] also reported 8-10% improvement in germination due to magnetic seed treatment and concluded that it could be helpful to farmers for increasing yield and reducing cost of production.

5. CONCLUSION

It can be concluded that exposure of cabbage seeds to low (5 mT) and moderate (10 mT) strength magnetic field can be helpful to improve germination percentage, uniformity of germination, seedling vigor and thus uniform crop stand. Moreover, magnetic field exposure of cabbage seeds should be based on initial germination and vigor of seeds; less magnetic field strength and exposure time should be used for relatively high vigor seeds and long exposure time at low to moderate magnetic field strength for low vigor seeds. Biochemical processes, such as lipid peroxidation, enzymes inactivation and protein disintegration, involved in poor germination, vigor and seedling growth in response to longer duration of exposure and higher magnetic field strength need to be assessed.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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