Pak. J. Bot., 55(1): 367-377, 2023. DOI: http://dx.doi.org/10.30848/PJB2023-1(38)

PRE-EXPOSURE IMPACT OF ELECTROMAGNETIC FIELD RADIATION ON CARNATION PLANT GROWTH AND QUALITY CUT FLOWER PRODUCTION

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Abstract

The current research paper manifests the impact of the electromagnetic field radiation on prolongation of the vase life of carnation cut flowers. Carnation cuttings were pre-exposed to various EMF flux densities (50 Hz) viz., 0, 40, 60, 80, 100, 120, 140, 160, 180 and 200 mT via electromagnet. The optimal exposure time of the carnation cuttings with EMF was 10 minutes of duration. The think about concluded the best outcomes with EMF 160 mT flux density with reference to the plant growth, floral traits, and vase life extension. Thus the pre-exposure of the carnation cuttings to EMF radiation has a profound impact on its cut blooms vase life prolongation.

Key words: Carnation cv. Tabasco, Electromagnetic field (EMF), Vegetative growth, Flower growth, Antioxidants enzymes.

Introduction

Ornamental plants production and their improvement techniques are expanding around the world to uplift the floriculture industry. However due to the shorter vase life of the cut flowers, the growth of the floriculture industry is not that rapid like other agricultural industries. The core reason behind this limitation is the genetic and the environmental factors that effects the quality of the cut flowers thus hinders the growth of their marketability in international markets (Aalifar *et al*., 2020).

Carnation is one of the top most five cut flowers in the world that ranks second to rose and also known as a Royal flower. Carnations are also well known as pinks and are the essential display blooms of the Royal weddings for bouquets and boutonnieres arrangements. Like roses and chrysanthemums, various fragrant and non-fragrant varieties of the carnations are used for garden cultivation, medicinal purpose, perfume industry and to garnish the food items. However it has a climacteric nature that cause its early senescence succeeding shorter vase life via natural ethylene emission in the gynoecium and the petal tissues (Hamidimoghadam *et al*., 2014; Mor *et al*., 1980; Naing *et al*., 2017; Roshani *et al*., 2016, Ayesha *et al*., 2020, Aalifar *et al*., 2020). By means of various pulse solutions, many researchers have promoted the vase life of the ethylene sensitive cut flowers like carnations. However, the impact of the non-ionization radiation such as the electromagnetic field effect on quality cut blooms production is still ignorant. As because of the magnetoreception properties of the plants, electromagnetic fields are capable of penetrating the biological tissues of the plants due to the presence of essential elements of different magnetic behaviors. The premise of plants interaction with external magnetic fields is the change in the orbiting movement of the electrons around the atoms of the essential elements (Maffei, 2014; Martinez & Carbonell, 2000; Dhawi *et al*., 2009; Johnson & Guy, 1972; Kaufman & Michaelson, 1974; Zare *et al*., 2015, Upadhyaya *et al*., 2022, Radzevicius *et al*., 2022). Thus in the vicinity of the external magnetic field, the unpaired electrons of the living cells align in its direction and polarize the dipoles of the cells subsequently stimulates the plant growth and development, gene expression, ions and water take-up, cell proliferation, enzymes activation, and early onset of flowering (Jain *et al*., 2015, Tang *et al*., 2018, Upadhyaya *et al*., 2022, Radzevicius *et al*., 2022, Judickaite *et al*., 2022).

Electromagnetic fields produce reactive oxygen species in the cell membranes and meddle with the formative processes in the plants at the cellular level (Kivrak *et al*., 2017, Tang *et al*., 2018, Upadhyaya *et al*., 2022, Radzevicius *et al*., 2022). Any developmental variation at the cell level is the result of a match or mismatch of external magnetic field with the phase of the cell's oscillators (Dhawi *et al*., 2009; El-Gizawy *et al*., 2016, Upadhyaya *et al*., 2022, Judickaite *et al*., 2022). Consequently, magnetically treated plants grow at their full energy rate through the transformation of magnetic energy into internal electrical energy and by increment in the electro-potential of the biomembranes (El-Gizawy *et al*., 2016; Tang *et al*., 2018**,** Vasilevski, 2003, Judickaite *et al*., 2022). Whereas, the magnetic fields are capable of synthesizing the antioxidant enzymes such as superoxidase, peroxidase, and catalase (Asghar *et al*., 2016; Rochalska & Grabowska, 2007, Tang *et al*., 2018, Judickaite *et al*., 2022) which is helpful in uplifting the poor vase holding periods of cut blooms. In this manner by keeping in view the keen functionalities of the EMF, the current research study was purposed to assess its impact on plant growth and the vase life of the carnation cv. Tabasco.

Materials and Methods

Freshly prepared cuttings of Sim carnation cv. Tabasco (5-10 cm having 3-5 nodes) were taken from Horticulture Research Institute for Floriculture and Landscaping, Rawalpindi, Pakistan and utilized as treatment plant material. Cuttings were first disinfected with a fungicide mix viz., Bavistan (0.1%) + Diathane M-45 (0.25%) for 5-6 minutes to avoid any fungal infection. After disinfection, the plant material was treated with different flux densities of extremely low frequency electromagnetic field (ELF-EMF 50 Hz) viz., 0, 40, 60,

80, 100, 120, 140, 160, 180 and 200 mT for 10 minutes. Model specifications of EMF generating system was comprised of an electromagnet (Serial no. 8440/20, Newport Pagnell England Electromagnet type-C); a regulated DC power supply of model PAD (250-4.5 L; 0-250 V; 4.5 A) Kikusi Electronics Cors., and a digital teslameter (MG-5DAR, MG-5DP Portable Hall Effect Gaussmeters) to measure the desired flux density between air space of electromagnet poles. Desired EMF flux density was changed by changing the current and voltage. Cuttings were exposed between the poles by keeping inside the glass test tube having 1 ml water to keep them fresh (Jamil *et al*., 2012; Shabrangi & Majd, 2009).

Before propagation, the cuttings ends were dipped in the indole butyric acid (IBA) 2500 ppm rooting hormone for 5 seconds to initiate roots. In lath house under low polythene tunnel cuttings were propagated in pots contained a mixture of coarse sand and well rottened farm yard manure in ratio (2:1). Before transplantation soil was analyzed for physical, chemical, and nutritional status (Table 3). Plants of 4-leaf stage were transplanted in large polythene bags (37 cm x 26 cm). Bags were comprised of uniform loam soil mixture and well rottened farm yard manure in ratio (2:1).

Plant morphological growth measurement: Plant height (cm) was recorded by means of a measuring tape from the base of the plant at soil level to the top of the plant. Number of leaf pairs per plant was counted by visual observation. Leaf chlorophyll contents (SPAD units) were measured from randomly selected three leaves (top, middle and lower) per plant per replication via SPAD-502 chlorophyll-meter (Minolta Camera Co. Ltd., Osaka, Japan). The mumber of the side shoots was counted per plant by visual observation.

Postharvest quality analysis

Percentage of flowers opening (%): Percentage of flowers opening (100%) was measured by daily count on the fully opened non wilted flowers to the total number of initial flower buds per inflorescence (Satoh *et al*., 2005). Fresh weight (g) of five flowers per replication was measured on electrical balance. Dry weight of the flowers (g) was measured on electrical balance from the same flowers taken for fresh weight analysis. They were dried in oven at 60ºC for one day for aforementioned analysis.

Vase life of cut flowers (days): The vase life of the carnation cut flowers was measured with slight modifications by following the method prescribed by (Satoh *et al*., 2005). One inflorescence having 4-5 buds or flowers was cut in slanting shape at its base. Every inflorescence was at least consisted of one top open brush bud and was placed in 250 ml distilled water in glass bottles. The vase life of cut carnation flowers was measured in days starting from first day by assessing the senescing symptoms including discoloration, petal in-rolling, desiccation and total wilting of the flowers. The observations were recorded on daily basis till complete senescence of the petals. Distilled water of the bottles was changed every three days later to avoid any bacterial contamination. Experiment for each treatment was repeated three times to take an average record. Vase analysis was carried out under 14 hour illumination and at $25^{o}C \pm 5$ room temperature (Satoh *et al*., 2005).

Ethylene emission (ppm): Ethylene (C_2H_4) emission was measured from carnation flowers in postharvest condition via ethylene analyzer (ICA56 Ethylene Analyser). Three flowers of carnation were put in 450 ml jars in such a way that each flower was placed in separate jar. The flowers were kept in jars for 1 hour while keeping the lids sealed with sealing tape. Ethylene concentration was measured after 1 hour by inserting the hypodermic syringe inside the jars through rubber septum on the lid (Satoh *et al*., 2005). Ethylene emission was measured in fully opened flowers.

Membrane integrity (%): Membrane integrity of carnation cut flower was measured by following the method of (Singh *et al*., 2008). Slight modification in protocol was implied. Five petals of carnation flower per replication of 1 cm size were washed in distilled water for about 1 minute. Petals were dried on filter paper, and inserted altogether into test tube having 10 ml of distilled water. Petals were incubated in this condition at 25°C for 180 minutes. After incubation initial electrolyte leakage was deducted by using a conductivity meter. Solution was autoclaved at 121°C for 15 minutes to isolate all the electrolytes out from the petals before the final conductivity (total electrolyte leakage) be found. Membrane integrity was measured in fully opened flowers in postharvest condition.

The % membrane integrity was calculated as follow. Membrane Integrity (%) = [1 - (Electrolyte leakage after 180 min of incubation /Total electrolyte leakage)] x 100.

Antioxidant enzymes analysis

Preparation of cell free enzyme extract: Two grams of the frozen sample of carnation flower preserved at $-80^{o}C$ temperature in extra low refrigerator was used for analysis which was grinded immensely in pre-chilled mortar and pestle. Sample was suspended in 5 ml of 0.1 M KPO_4 (pH 7.8) having 0.2 g Polyvinyl pyrrolidone (PVP) and 0.5% Triton. Mixture was centrifuged in centrifuge machine (HERMLE Z 200 A) at 14000 rpm for 30 minutes at $4^{o}C$ (Abassi *et al*., 1998).

Superoxide dismutase (SOD): SOD enzyme activity was assayed by measuring inhibition of photochemical reduction of nitro blue tetrazolium (NBT) using method of (Abassi *et al*., 1998) with few modifications. Two sets of five cuvettes were used, each containing 0, 50, 100, 200, or 300 µl enzyme extract and 13 mM Methionine, 75 µM NBT, 0.1 mM EDTA and 2 µM riboflavin (substrate) was added to each reaction cuvette and transposed to allow maximum contact of enzyme with substrate. One set of cuvette was covered with black cloth as control. Other set was placed under fluorescent lamps. Light absorbance was measured at 560 nm with spectrophotometer (Optima@3000). One unit of SOD defined as amount of enzyme that inhibits activity of NBT photo reduction by 50% under assay conditions. One enzyme unit was expressed as units g^{-1} protein.

Peroxidase (POD): Peroxidase (POD) activity of cut flowers was determined according to the method prescribed by (Hassan *et al*., 2007) with few modifications. The assay mixture was comprised of 15 mM Na_3PO_4 buffer (pH 6.0) and 100 µl substrate, which contained 0.1 mM guaiacol (O-methoxyphenol) and 1 mM H_2O_2. At wavelength of 470 nm, the absorbance of reaction mixture was measured through spectrophotometer. POD activity was calculated as change in optical density (OD) over a three-minute period and expressed as units per gram fresh weight (U g^{-1} f w).

Catalase (CAT): The CAT enzyme activity was determined via method of (Abassi *et al*., 1998). By using two buffer solutions, the reaction was carried out. First solution (buffer A) was consisted of 50 mM KPO_4 buffer (pH 7.0) while second solution (buffer B) was consisted of 12.5 mM H_2O_2 in 50 mM KPO_4 buffer (pH 7.0). A 100 µl enzyme extract was added to each of two cuvettes, one containing 1 ml buffer-A and other containing 1 ml buffer-B. Both cuvettes were placed in the dark. Through spectrophotometer, the optical density (OD) at 240 nm was then being recorded at 45 sec and 60 sec starting from the time the extract was added to the cuvettes. The difference in optical density between 45 and 60 sec reading was used to calculate CAT activity. One unit CAT activity was expressed in units per gram fresh weight (U g^{-1} f w).

Experiment was laid down in Completely Randomized Design (CRD) comprised of 3 replications per treatment and 10 plants per replication per treatment. Data recorded for growth, physiological and postharvest parameters was analyzed statistically via analysis of variance (ANOVA) and variations among treatment means were compared through LSD at 5% probability level.

Results

Influence of EMF flux densities on morphological plant and flower features: The statistical analysis of the growth parameters viz., plant height, the number of leaf pairs, leaf chlorophyll contents, and the number of side shoots revealed the statistically significant improvement at extremely low-frequency electromagnetic field (ELF-EMF) pre-exposure as compared to control. The most remarkable difference was observed with 160 mT EMF flux density (Table 1). Minimum values were recorded in control.

Floral peculiarities: All floral parameters statistically showed the significant changes for pre-exposed (ELF-EMF) flux densities as compared to control. Minimum number of days taken to first flower initiation, maximum flower diameter, flower stalk length and diameter, flower yield, flower fresh, and dry weight was measured with 160 mT EMF (Table 2) as compared to control.

Postharvest quality parameters: Statistically postharvest parameters of carnation cut flowers viz., percentage of 100 % flowers opening, vase life (days), ethylene production (ppm), and membrane integrity (%) showed the most pronounced effects with EMF at 160 mT flux density (Table 3). Reduction in ethylene production, increment in membrane integrity of flowers, cut flowers vase life extension, and maximum percentage of flowers opening was recorded with 160 mT flux density as compared to control.

Table 1. Impact of various EMF flux densities on carnation growth parameters.

EMF flux density (mT)	Plant height (cm)	No. of leaf pairs	Leaf chlorophyll contents (SPAD units)	No. of side shoots
Control	51.0 f ± 2.64 49 ± 54	44.6 f ± 2.08 43 ± 47	23.0 e ± 1.95 20.9 ± 24.8	5.33 e ± 0.57 5 ± 6
40	56.0 de ± 1.84 54 ± 57.6	47.6 ef ± 1.52 46 ± 49	26.3 f ± 2.51 24 ± 29	6.33 e ± 0.57 6 ± 7
60	57.3 cde ± 1.52 56 ± 59	48.6 de ± 1.52 47 ± 50	36.0 e ± 1.73 34 ± 37	8.33 cd ± 0.57 8 ± 9
80	58.3 bcd ± 1.15 57 ± 59	52.0 d ± 1 51 ± 53	40.0 d ± 1 39 ± 41	8.66 bcd ± 0.57 8 ± 9
100	59.3 bc ± 1.15 58 ± 60	56.6 c ± 4.04 53 ± 61	43.0 cd ± 1 42 ± 44	9.33 bc ± 0.57 9 ± 10
120	59.6 bc ± 1.15 59 ± 61	61.6 b ± 2.30 59 ± 63	46.0 bc ± 1 45 ± 47	10.3 ab ± 1.15 9 ± 11
140	60.6 b ± 0.57 60 ± 61	68.0 a ± 1 67 ± 69	47.3 b ± 0.57 47 ± 48	10.3 ab ± 2.08 8 ± 12
160	68.0 a ± 2.64 65 ± 70	71.3 a ± 0.57 71 ± 72	56.0 a ± 5.19 50 ± 59	11.3 a ± 1.52 10 ± 13
180	54.8 e ± 1.02 54 ± 56	61.0 b ± 3.60 58 ± 65	46.6 bc ± 1.52 45 ± 48	10.0 abc ± 1.73 9 ± 12
200	51.3 f ± 1.15 50 ± 52	57.0 c ± 2.64 54 ± 59	41.5 d ± 0.96 40.4 ± 42.0	7.00 de ± 1 6 ± 8
LSD value	1.32	1.87	1.76	0.95

*Mean values of a parameter in the respective column having different letters shows significant difference at (p<0.05) among various EMF treatments

Table 2. Impact of various EMF flux densities on carnation floral parameters.

EMF flux density (mT)	No. of days taken to first flower opening	Flower diameter (cm)	Flower stalk length (cm)	Flower stalk diameter (mm)	Flowers yield per plant	Fresh weight of the flowers (g)	Dry weight of the flowers (g)
Control	77.0 a ± 0 77 ± 77	3.45 g ± 0.72 2.62 ± 3.96	39.7 g ± 3.80 35.8 ± 43.4	2.77 e ± 1.02 2.16 ± 3.96	2.86 f ± 0.11 2.80 ± 3.00	12.6 f ± 2.08 10.2 ± 14.0	2.93 h ± 0.64 2.20 ± 3.40
40	61.0 b ± 1.73 59 ± 62	3.90 fg ± 0.23 3.64 ± 4.10	46.5 f ± 2.50 44 ± 49	3.62 de ± 0.17 3.44 ± 3.78	3.13 ef ± 0.41 2.80 ± 3.60	15.4 ef ± 1.73 13.4 ± 16.4	3.80 g ± 0.17 3.60 ± 3.90
60	59.0 c ± 0 59 ± 59	4.54def ± 0.10 4.44 ± 4.64	51.0 e ± 1.31 49.6 ± 52.2	3.92 cd ± 0.31 3.56 ± 4.15	3.53 de ± 0.75 3.00 ± 4.40	15.8 de ± 3.21 12.2 ± 18.2	4.56 f ± 0.49 4.00 ± 4.90
80	59.3c ± 0.5774 59 ± 60	4.45 def ± 0.39 4.14 ± 4.90	53.6cde ± 3.30 50.4 ± 57	4.37bcd ± 0.19 4.15 ± 4.52	4.06 cd ± 0.11 4.00 ± 4.20	17.7 de ± 0.32 17.4 ± 18.0	5.20 e ± 0.17 5.00 ± 5.30
100	57.0 d ± 0 57 ± 57	4.92 cd ± 0.64 4.32 ± 5.60	55.8bcd ± 1.41 54.6 ± 57.4	4.59bc ± 0.91 4.00 ± 5.64	4.26 c ± 0.30 4.00 ± 4.60	17.5 de ± 1.74 15.6 ± 19.0	6.16 cd ± 0.15 6.00 ± 6.30
120	57.0 d ± 0 57 ± 57	5.39 bc ± 0.40 4.94 ± 5.70	57.6 bc ± 0.70 57 ± 58.4	5.18 ab ± 0.28 5.02 ± 5.52	4.40 c ± 0.40 4.00 ± 4.80	19.0 cd ± 3.12 15.4 ± 21.0	6.66 bc ± 0.20 6.50 ± 6.90
140	56.3 d ± 0.57 56 ± 57	6.00b ± 0.35 5.60 ± 6.24	59.2 ab ± 1.24 57.8 ± 60.2	5.62a ± 0.33 5.24 ± 5.84	5.06 b ± 0.30 4.80 ± 5.40	23.3 ab ± 0.88 22.6 ± 24.3	7.03 b ± 0.15 6.90 ± 7.20
160	52.3 f ± 0.57 52 ± 53	7.61a ± 0.21 7.42 ± 7.84	62.1 a ± 0.50 61.6 ± 62.6	6.00 a ± 0.26 5.72 ± 6.24	7.06 a ± 0.11 7.00 ± 7.20	26.0 a ± 2.00 24 ± 28	7.86 a ± 0.41 7.40 ± 8.20
180	54.0 e ± 0 54 ± 54	4.72cde ± 0.29 4.42 ± 5.00	53.2 de ± 2.54 51.6 ± 56.2	3.79 cd ± 0.24 3.53 ± 4.02	4.53 bc ± 0.30 4.20 ± 4.80	23.2 ab ± 0.52 22.8 ± 23.8	6.13 cd ± 0.55 5.60 ± 6.70
200	56.0 d ± 0 56 ± 56	4.24ef ± 0.05 4.18 ± 4.28	50.5 ef ± 4.16 47.2 ± 55.2	3.69d ± 0.29 3.37 ± 3.95	4.20 c ± 0.20 4.00 ± 4.40	22.0 bc ± 1.00 21.1 ± 23.1	5.90 d ± 0.20 5.70 ± 6.10
LSD value	0.51	0.32	2.02	0.40	0.29	1.56	0.29

*Mean values of a parameter in the respective column having different letters shows significant difference at p (<0.05) among various EMF treatments

Table 3. Impact of various EMF flux densities on postharvest attributes of carnation cut flower.

EMF flux density (mT)	Percentage of flowers opening (100%)	Vase life (Days)	Ethylene production (ppm)	Membrane integrity (%)
Control	37.7 i ± 0.18 37.6 ± 38.0	6.66 g ± 0 6.66 ± 6.66	9.33 a ± 0.05 1.80 ± 1.90	61.4 fg ± 4.43 57.6 ± 66.3
40	48.8 h ± 0.13 48.7 ± 49.0	6.66 g ± 0.33 6.33 ± 7	8.13 ab ± 0.05 1.50 ± 1.60	60.5 g ± 6.55 56 ± 68.1
60	60.5 f ± 0.46 60.0 ± 60.81	7.88 f ± 0.38 7.66 ± 8.33	6.63 bc ± 0.05 1.40 ± 1.50	64.2 defg ± 3.80 60 ± 67.3
80	64.6 e ± 1.64 63.3 ± 66.5	8.66 e ± 0.57 8 ± 9	6.20 bcd ± 0 1.40 ± 1.40	66.0 cdef ± 3.29 63.6 ± 69.8
100	67.8 d ± 2.91 64.5 ± 70.1	9.88 cd ± 0.50 9.33 ± 10.3	4.70 cde ± 0.10 1.30 ± 1.50	68.5 bcd ± 0.84 67.6 ± 69.3
120	74.3 c ± 0.53 74.0 ± 75.0	10.4 c ± 0.50 10 ± 11	4.20 de ± 0.11 1.30 ± 1.50	70.3 bc ± 1.52 69 ± 72
140	77.9 b ± 2.80 75.4 ± 81.0	11.7 b ± 0.38 11.3 ± 12	3.80 e ± 0.15 1.10 ± 1.40	72.1 ab ± 0.45 71.8 ± 72.6
160	91.5 a ± 0.77 90.6 ± 92.0	12.6 a ± 0.33 12.3 ± 13	3.66 e ± 0.15 0.90 ± 1.20	75.8 a ± 0.81 75 ± 76.6
180	60.6 f ± 0.34 60.3 ± 60.9	9.55 d ± 0.50 9 ± 10	5.30 cde ± 0.30 0.80 ± 1.40	67.2 bcde ± 2.22 64.6 ± 68.6
200	52.4 g ± 1.20 51.6 ± 53.8	8.44 ef ± 0.50 8 ± 9	6.63 bc ± 0.05 1.30 ± 1.40	62.4 efg ± 1.92 60.3 ± 64.1
LSD value	1.20	0.35	0.99	2.58

*Mean values of a parameter in the respective column having different letters shows significant difference at p (<0.05) among various EMF treatments

Table 4. Impact of various EMF flux densities on SOD, POD, and CAT enzyme activity in carnation cut flower.

Treatment	Post-harvest stage		SOD	POD	CAT
0	Open brush bud	Mean ±SD	8 ± 1	3.60 ± 0.70	1.73 ± 0.46
		Min - Max	7 ± 9	2.90 ± 4.30	1.19 ± 2
	Fully opened flower	Mean ± SD	16.7 ± 0.40	6.56 ± 0.30	2.23 ± 0.01
		Min - Max	16.3 ± 17	6.30 ± 6.90	2.22 ± 2.25
	Onset senescence	Mean ± SD	3.50 ± 0.55	0.86 ± 0.25	0.80 ± 0.10
		Min - Max	3 ± 4.10	0.60 ± 1.10	0.70 ± 0.90
40	Open brush bud	Mean ± SD	10.3 ± 0.52	7.03 ± 0.15	2.08 ± 0.01
		Min - Max	9.90 ± 10.9	6.90 ± 7.20	2.07 ± 2.10
	Fully opened flower	Mean ± SD	18 ± 0.40	10.8 ± 0.15	2.53 ± 0.01
		Min - Max	17.6 ± 18.4	10.7 ± 11	2.52 ± 2.55
	Onset senescence	Mean ± SD	10 ± 0.15	5.26 ± 0.15	2.07 ± 0.01
		Min - Max	9.90 ± 10.2	5.10 ± 5.40	2.06 ± 2.09
60	Open brush bud	Mean ± SD	11 ± 0.47	8.20 ± 0.10	2.20 ± 0.10
		Min - Max	10.5 ± 11.4	8.10 ± 8.30	2.10 ± 2.30
	Fully opened flower	Mean ± SD	19.2 ± 0.34	11.5 ± 0.32	2.54 ± 0.01
		Min - Max	19 ± 19.6	11.3 ± 11.9	2.53 ± 2.55
	Onset senescence	Mean ± SD	10.2 ± 0.36	5.93 ± 0.35	2.04 ± 0.02
		Min - Max	9.80 ± 10.5	5.60 ± 6.30	2.02 ± 2.07
80	Open brush bud	Mean ± SD	13 ± 0.41	8.80 ± 0.10	2.21 ± 0.02
		Min - Max	12.6 ± 13.4	8.70 ± 8.90	2.19 ± 2.24
	Fully opened flower	Mean ± SD	19.3 ± 1.52	12.1 ± 1.75	2.56 ± 0.01
		Min - Max	18 ± 21	10.5 ± 14	2.56 ± 2.57
	Onset senescence	Mean ± SD	10.5 ± 0.45	6.80 ± 0.26	2.10 ± 0.01
		Min - Max	10.1 ± 11	6.50 ± 7	2.09 ± 2.11
100	Open brush bud	Mean ± SD	13.4 ± 0.25	9.13 ± 0.20	2.12 ± 0.01
		Min - Max	14.5 ± 15	8.90 ± 9.30	2.11 ± 2.14
	Fully opened flower	Mean ± SD	21.1 ± 0.76	13.7 ± 0.46	2.53 ± 0.07
		Min - Max	20.5 ± 22	13.5 ± 14.3	2.45 ± 2.58
	Onset senescence	Mean ± SD	10.9 ± 0.60	6.83 ± 0.30	2.13 ± 0.01
		Min - Max	10.2 ± 11.3	6.50 ± 7.1	2.12 ± 2.14
120	Open brush bud	Mean ± SD	15.3 ± 0.20	9.93 ± 0.15	2.14 ± 0.01
		Min - Max	15.2 ± 15.6	9.80 ± 10.1	2.13 ± 2.16
	Fully opened flower	Mean ± SD	21.3 ± 1.82	15.2 ± 1	2.60 ± 0.01
		Min - Max	19.4 ± 23	14.2 ± 16.2	2.59 ± 2.61
	Onset senescence	Mean ± SD	11.4 ± 0.10	7.1 ± 0.10	2.13 ± 0.02
		Min - Max	11.3 ± 11.5	7 ± 7.2	2.11 ± 2.15
140	Open brush bud	Mean ± SD	15.5 ± 0.41	10.6 ± 0.10	2.18 ± 0.01
		Min - Max	15.1 ± 15.9	10.5 ± 10.7	2.17 ± 2.20
	Fully opened flower	Mean ± SD	22.6 ± 0.40	16.2 ± 0.95	2.68 ± 0.01
		Min - Max	22.3 ± 23.1	15.3 ± 17.2	2.67 ± 2.70
	Onset senescence	Mean ± SD	11.8 ± 0.10	7.13 ± 0.25	2.16 ± 0.01
		Min - Max	11.7 ± 11.9	6.90 ± 7.40	2.15 ± 2.17
160	Open brush bud	Mean ± SD	16.3 ± 0.15	11.9 ± 0.20	2.43 ± 0.15
		Min - Max	16.2 ± 16.5	11.8 ± 12.2	2.30 ± 2.60
	Fully opened flower	Mean ± SD	24.4 ± 1.73	17.3 ± 0.96	2.84 ± 0.01
		Min - Max	22.5 ± 25.8	16.3 ± 18.2	2.83 ± 2.85
	Onset senescence	Mean ± SD	12 ± 0.15	7.66 ± 0.15	2.18 ± 0.01
		Min - Max	11.9 ± 12.2	7.50 ± 7.80	2.17 ± 2.19
180	Open brush bud	Mean ± SD	14.4 ± 0.34	11.1 ± 0.10	2.11 ± 0.01
		Min - Max	14.2 ± 14.8	11 ± 11.2	2.10 ± 2.13
	Fully opened flower	Mean ± SD	20.7 ± 0.58	15.6 ± 1.59	2.79 ± 0.01
		Min - Max	20.1 ± 21.2	14.3 ± 17.4	2.78 ± 2.80
	Onset senescence	Mean ± SD	10 ± 0.10	6.73 ± 0.30	1.53 ± 0.15
		Min - Max	9.90 ± 10.1	6.40 ± 7	1.40 ± 1.70
200	Open brush bud	Mean ± SD	13.7 ± 0.32	10.7 ± 0.20	1.49 ± 0.52
		Min - Max	13.4 ± 14	10.6 ± 11	1.18 ± 2.10
	Fully opened flower	Mean ± SD	21.1 ± 1.20	14.4 ± 0.62	2.77 ± 0.01
		Min - Max	20 ± 22.4	13.9 ± 15.1	2.76 ± 2.79
	Onset senescence	Mean ± SD	10.1 ± 0.47	6.16 ± 0.05	1.19 ± 0.11
		Min - Max	9.8 ± 10.7	6.10 ± 6.20	1.07 ± 1.30

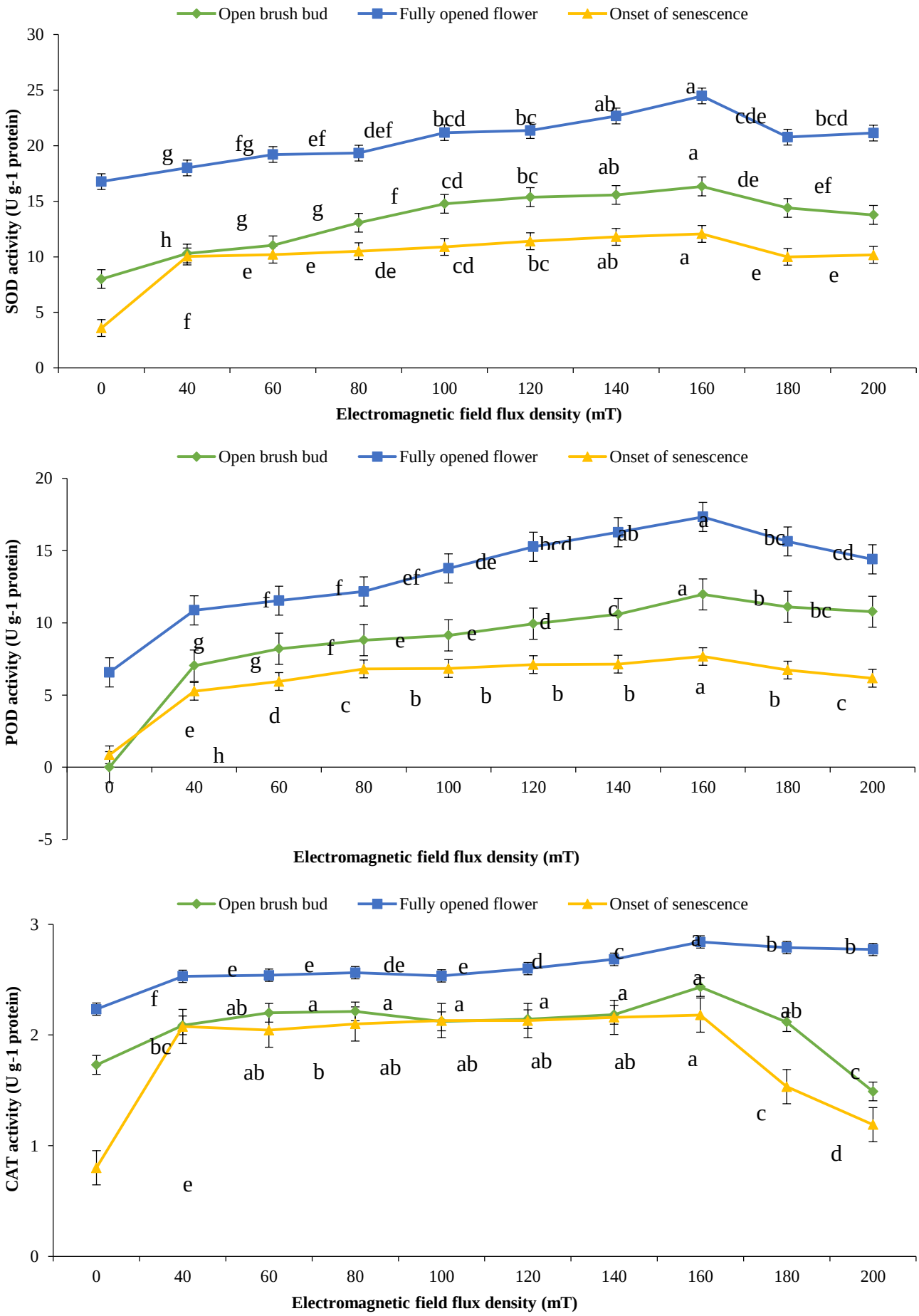

Fig. 1. Influence of various EMF flux densities on SOD, POD & CAT enzyme activity in carnation cut flowers.

Antioxidant enzymes Activities: According to the statistical point of view, EMF with 160 mT flux density revealed the significant improvement in antioxidant enzymes viz., SOD, POD, and CAT of carnation cut flowers at open brush bud, fully opened flower, and at the onset of senescence stage as compared to control (Table 4 & Fig. 1).

Discussion

In current findings, the advancement in the plant characters takes put due to the profound penetration power of low-frequency magnetic fields in plant tissues (Aleman *et al*., 2014; Pittman, 1963, Aalifar *et al*., 2020, Upadhyaya *et al*., 2022, Radzevicius *et al*., 2022). As plants have the magnetic constitutions, therefore the essential mode of action of the magnetic fields is the induction of the electrical charges and currents and influence on the nuclear spins of the paramagnetic molecules possesed by the plants (Zare *et al*., 2015, Upadhyaya *et al*., 2022, Radzevicius *et al*., 2022). Magnetic radiations (MF and EMF) worked to align the free electrons of the plant cells together with the polarization of dipoles, consequently, impacted the cell division, elongation, and vascular differentiation.

Among distinctive capacities, magnetic radiation can produce the surface charges on cell membranes hence make the surface signals. Changes happened across the cell membrane's ionic streams density and in intracellular Ca^{+2} levels that caused alteration in osmotic pressure and changed the capacity of the plant tissues to assimilate water (Tahir & Karim, 2010, Choi *et al*., 2021, Upadhyaya *et al*., 2022, Radzevicius *et al*., 2022, Grinberg *et al*., 2022). Protein channels in the cell membranes perturbed and perforated by magnetic radiation, therefore made an easy consumption of nutrients and water taking after the strides plant development and advancement. Since low-frequency magnetic fields actuate more osmotic pressure in cells so, they quicken the length of the plant (Sangeetha, 2016; Yamashita *et al*., 2004, Choi *et al*., 2021, Upadhyaya *et al*., 2022, Radzevicius *et al*., 2022). In current study, the EMF may well be enhanced the development of the plants due to outperform enzymatic action, variety in assimilates transport, and an alter in the growth regulators (Leelapriya *et al*., 2009, Upadhyaya *et al*., 2022, Choi *et al*., 2021, Aalifar *et al*., 2020, Judickaite *et al*., 2022, Radzevicius *et al*., 2022).

The electromagnetic field is able of producing the free radicals thus interferes with the cellular functions. Plasma membrane's receptors are the targets of magnetic field interaction (Kivrak *et al*., 2017, Upadhyaya *et al*., 2022, Aalifar *et al*., 2020, Judickaite *et al*., 2022, Choi *et al*., 2021, Radzevicius *et al*., 2022). Due to paramagnetic properties of the chloroplasts, the light-harvesting complex-II of thylakoid membrane is sensitive to magnetic stress (Racuciu *et al*., 2007, Choi *et al*., 2021). Magnetic stress alters the biochemistry and the measure of chloroplasts. They effectively situate within the heading of connected magnetic field causing a rise in the inner plant body temperature taking after the chlorophyll substance formation hence upgrade the photosynthesis. Due to magnetic oxidative stress, Rubisco (Ribulose-1, 5-bisphosphate carboxylase/oxygenase) enzyme expanded hence, carbon absorption and CO_2 obsession to carbohydrates accelerated (Dhawi & Al-Khayri, 2008; Dhawi, 2014; Feller *et al*., 2008; Tian *et al*., 1989, Choi *et al*., 2021, Radzevicius *et al*., 2022). An increment in the photosynthetic pigments associated with modification of gene transcription or cytokinin synthesis together with auxin synthesis after magnetic field treatment was found in soybean plants through magnetic water treatment (Hozayn *et al*., 2013). Cytokinin produced via magnetic treatments takes portion in chloroplast advancement and nutrients metabolism. Increment in indole acetic acid (IAA) created by the magnetic application affected the chloroplast development (Hozayn *et al*., 2010). EMF impact the calcium ions subsequently affect the developmental process and plant growth regulators viz., auxin, and cytokinins. In this way, auxin progresses the stem development and cytokinin encourages the mitosis to prepare (Angaji *et al*., 2014).

Furthermore, the plants contain the phyto-ferritins in tissues. Phyto-ferritin being an iron storage protein having 4500 Fe atoms is one of the reasons that plants respond to external magnetic fields. EMF interaction with the last spin moment of ferritin cells creates an oscillation in the system. Oscillation energy dissipates and finally adjusts into the direction of the applied magnetic field subsequently increase the effective temperature of the magnetic spin of plant's system hence enhance the plant's internal temperature. An increment in the internal temperature happens amid the initial minutes of the magnetic field treatment to influence the physiological processes (Vaezzadeha *et al*., 2006).

In prior studies, magnetic stress caused an increase in ferritin production in chloroplasts and invigorated the photosynthesis process (Briat *et al*., 2010; Vaezzadeha *et al*., 2006; Zielinska-Dawidziak, 2015, Upadhyaya *et al*., 2022, Choi *et al*., 2021, Aalifar *et al*., 2020, Judickaite *et al*., 2022). Important action of the external magnetic field induces force on plant containing diamagnetic water and takes off it vibrating driving water subordinate activities excitement causing the rising rate of sap to be improved making plant throbbing. Plant throb in such cases improves the chlorophyll synthesis (Saxena *et al*., 1966). Magnetic fields influenced the production of proteins, carbohydrates, free radicals, and enzymes alongside the incitement of photosynthesis prepare, chlorophyll and other food pigments generation, CO_2 assimilation, nutrients pumping, and the water take-up by plants (Dhawi *et al*., 2009; Leelapriya *et al*., 2009; Nagy *et al*., 2005, Upadhyaya *et al*., 2022, Choi *et al*., 2021, Aalifar *et al*., 2020, Judickaite *et al*., 2022).

A brief review on earlier studies manifested the impact on lots of crops species e.g. in onion plant, magnetic treatment has already improved the length of the seedlings and roots, and leaf area except for the number of leaves (De Souza *et al*., 2014). Whereas the EMF exposure promoted the average height of the shoots, and the length of the roots in lupin and zinnia plant (Mroczek-Zdyrska *et al*., 2016; Zamiran *et al*., 2013). In case of the rice crop, the acute gamma

irradiation effected the plant physiology (Choi *et al*., 2021). However, the MF exposure extended the gladiolus root and shoot tip development, and by and large development design of the plants (Cantor *et al*., 2002). Shoot height, and the number of leaves/branches were improved by EMF treatment in okra and cucumber plant (Ayyub *et al*., 2012; Rezaiiasl *et al*., 2012). Pregermination magnetic treatment of potato eyes enhanced the plant's top growth (Pittman, 1972). Likewise, an increment in the number of roots and stem length, the number of nodes and nodes length was observed in pre-exposed grapes cuttings with ELF-EMF (Dardeniz *et al*., 2006). Chlorophyll pigments were increased in parenchyma tissues of corn and in the leaves of sugar beet, potato, soybean, date palm seedlings, and corn plants via EMF exposure (Dhawi & Al- Khayri, 2009; Javed *et al*., 2011; Racuciu *et al*., 2007; Racuciu *et al*., 2009; Rivero *et al*., 2016, Upadhyaya *et al*., 2022, Choi *et al*., 2021, Aalifar *et al*., 2020, Judickaite *et al*., 2022).

In current research study, the impact on floral parameters of carnation plant is linked with the vegetative growth improvements. Early flower initiation is correlated with biomass amassing and translocation at the time of reproductive phase transition by means of magnetic field application. Early flower initiation due to biomass enhancement was found in Arabidopsis under GMF environment (Maffei, 2014). Besides, plants moreover carry blue light receptor protein called cryptochrome which is actually magneto-sensitive in nature and involves regulation of flowering through the production of gibberellic acid by magnetic field effect. It was found that functions of cryptochrome were modified near-null magnetic field counting phosphorylation and dephosphorylation in Arabidopsis species causing a delay in blooming via suppression of GA_3 production (Xu *et al*., 2017, Aalifar *et al*., 2020).

Affected reproductive growth by EMF accredited by active chlorophyll production taking after the incredible light-harvesting driving photosynthesis stimulation, higher CO_2 fixation, more water influx and translocation of photo assimilates in partition to reproductive organs for early blooming, increase in flower diameter, fresh weight, dry matter contents in flower, and flower yield per plant. In different findings, later plant development and yield influence of pre-exposed EMF was taken note through initial magnetic stimulation and redistribution of plant ions, molecules, charged particles, and hormonal activities (De Souza *et al*., 2014; Hurd & Enoch, 1976; Moussa, 2011; Rezaiiasl *et al*., 2012, Aalifar *et al*., 2020). Magnetic fields too impacted the calcium channels to actuate such changes (Belyavskaya, 2004, Grinberg *et al*., 2022). Whereas in numerous plant species, they augmented the cells with antioxidants at the seedling stage that served as nutrition for afterward plant growth, productivity, and quality yield production (Asghar *et al*., 2016, Upadhyaya *et al*., 2022, Choi *et al*., 2021, Aalifar *et al*., 2020, Judickaite *et al*., 2022). Magnetic fields impact the ion channels within cells, proteins formation, enzymes stimulation, and ATP hydrogen pump system to affect all plant growth parameters (De Souza *et al*., 2005, Upadhyaya *et al*., 2022, Choi *et al*., 2021, Aalifar *et al*., 2020, Judickaite *et al*., 2022, Grinberg *et al*., 2022). In onion crop, MF exposure enhanced its seedling dry weight, bulb weight, bulb yield per area, number of tunics per bulb, diameter of bulb, and bulb dry weight (De Souza *et al*., 2014).

Application of electric fields has improved the saffron attributes viz., bulb sprouting, flower weight, petal and stem length, stigma height, and weight (Abarghouei, 2014). Whereas, the early enlarged tomato fruit set was recorded with various EMF flux densities. EMF increased the corn yield and stem diameter (Zepeda-Bautista *et al*., 2010). In tomatoe crop, the dry matter contents of the plants, the number of flowers, fruit set, and fruit dry matter contents were enhanced (De Souza *et al*., 2005; Jedlicka *et al*., 2015). While, the pregermination magnetic exposure to potato eyes produced the plants with high yield (Pitman, 1972). In a research trial, the researchers found out the profound impact of the pre-seed exposure of MF on number of potato tubers, tuber fresh weight, tuber diameter, and collar diameter of sufed sirin and iple iple plants (El-Gizawy *et al*., 2016; Tanvir *et al*., 2012). Similarly, the improved stem thickness was observed in lentil plants at pre-exposed MF treatment (Shabrangi & Majd, 2009). In contrast, number of flowers and fruits, fruit weight, and fruit diameter was not influenced by the magnetic field exposure in cucumber (Rezaiiasl *et al*., 2012).

According to the prior trials, an early ageing of the cut flowers is associated with the ethylene release, membrane integrity, and antioxidant enzymes status of the cells. Thus, the control over ethylene production delays the senescence by strengthening the cell membranes (Kazemi *et al*., 2011). In current study, the force exerted by the EMF may be influenced the membrane strength and the water movement in water channels that ameliorated the membrane integrity of the produced carnation cut flowers. It was prior detailed to reduce the lipid peroxidation and the electrolyte leakage of the wheat seedlings (Payez *et al*., 2013). In the meantime, EMF also creates a stress on cells hence produces the ROS (Kivrak *et al*., 2017, Choi *et al*., 2021). However, it seems to overcome the free redicals stress by arousing the antioxidant enzymes (Maffie, 2014; Sharma *et al*., 2009, Choi *et al*., 2021). Low-frequency magnetic field was found to be exceptionality successful in reinforcing the plant defense framework (Pietruszewski *et al*., 2007, Maffei, 2014, Grinberg *et al*., 2022).

In the latest findings, ethylene production at its low concentration from the floral tissues as well as excellent antioxidants augmentation in tissues was promoted at 160 mT EMF flux density hence it might be the reason for the enhanced membrane integrity and drawn out vase life of the produced carnation cut flowers. Contrastingly, the magnetic field with or without gamma irradiation did not progress the shelf life of tomato fruits (Kumar *et al*., 2014). Secondly, the ethylene hormone is suggested to be a promoter of flower opening at low concentration but prevents the blooming at high level (Doorn & Kamdee, 2014, Cebrian *et al*., 2022). Due to low ethylene emanation and improvement in the antioxidant enzymes, it was deducted from the current consider that EMF at 160 mT flux density increased the percentage of flower opening. Contrastingly, bud break percentage of grape cv.

Uslu was not influenced by the pre-exposed ELF-EMF at 0.15 T for 10 and 20 minutes of cuttings exposure (Dardeniz *et al*., 2006).

Cut flower quality is keenly associated with the antioxidant enzymes viz., SOD, POD, and CAT which is essential for the protection of the plant tissues against the early senescence process due to over production of reactive oxygen species (ROS). SOD needs for (O^-_2) conversion to hydrogen peroxide (H_2O_2) molecules while CAT and POD break down these molecules into water and oxygen molecules thus protect the membranes from lipid peroxidation (Farzpourmachiani *et al*., 2013; Sharifzadeh *et al*., 2014, Aalifar *et al*., 2020). However, all such changes were earlier noticed by the scientists associated with MF treatments to the plant material that brought the biochemical changes in plants due to change in internal energy level, production of reactive oxygen species (ROS), protein gene expression, variation in ferromagnetic particles, and alteration in electron spins at the level of atom and molecule (Asghar *et al*., 2016).

Low magnetic field frequency of 50 Hz is the frequency at which various enzymatic reactions takes put and cells actuate their defense framework against stress (Pietruszewski *et al*., 2007, Aalifar *et al*., 2020). In early findings, magnetic stress impacted the redox status of plants by influencing the radical pair recombination (Maffei, 2014; Shabrangi & Majd, 2009; Zare *et al*., 2015, Aalifar *et al*., 2020). Principally, EMF exposure triggers the free radicals production in membranes during exposure time and upgrades the ROS concentration (Kivrak *et al*., 2017). In the interim, it compensates the oxidative stress by evoking anti-stress enzymes that indicates its mode of action in plants. In apoplasts, a weak MF involved in the antioxidant mediated reactions to overcome the redox imbalance (Maffie, 2014; Sharma *et al*., 2009, Aalifar *et al*., 2020).

In prior research studies, EMF made strides the CAT activity in *Valeriana officinalis* L. seeds (Farzpourmachiani *et al*., 2013). It raised the SOD enzyme activity in SOD enzyme exploratory trial (Buyukuslu *et al*., 2006). Magnetic fields are as now been demonstrated to impact the production of SOD, POD, CAT, and other enzymes in numerous plant species (Maffei, 2014, Aalifar *et al*., 2020). Activities of proteases, and α, $_\beta$-amylases were expanded upon the exposure of the mobile EMF in *Phaseolus aureus* Roxb (Sharma *et al*., 2009). The lycopene contents of the tomato fruits were raised across the pulsed magnetic pre-seed exposure (Efthimiadou *et al*., 2014). Whereas, the seed exposure of the *Satureia hortensis* L. with magnetic stress enhanced the α-amylase, dehydrogenase, and protease activity in its seedlings (Pourakbar & Hatami, 2012). In a MF research study, the peroxidase, acid phosphatase, α-amylase, nitrate reductase, alkaline phosphatase, and polyphenol oxidase activity in the pre-exposed seeds of the soybean was promoted (Radhakrishnan & Kumari, 2013).

Conclusions

In conclusion, the impact of the pre-exposure treatment of non-ionization radiation e.g. electromagnetic field (EMF) at 160 mT flux density profoundly affected the plant and flower growth features of the carnation. Whereas, the postharvest quality of the cut blooms was promoted via enhancement in the antioxidant enzymes viz., SOD, POD, and CAT and membrane integrity and by reduction in the ethylene gas emission. Therefore, the current findings could be used in the quality production of ethylene sensitive cut flowers like carnations for making them capable of export from Pakistan to the European countries where this cut flower is very much in demand for various purposes.

Acknowledgements

The current research study was supported by PMAS-Arid Agriculture University, Rawalpindi, Pakistan.

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(Received for publication 27 May 2021)