

Growth alteration of *Allium cepa* L. roots exposed to 1.5 mT, 25 Hz pulsed magnetic field

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Running Head: Growth alteration by pulsed magnetic field

ABSTRACT

The response of plants to magnetic fields (MF) is not fully understood. This work study the effects of pulsed MF on the germination and growth of *Allium cepa* roots. Onions were exposed to 25Hz, 1.5mT, 33h. Pulsed MF was generated by a Helmholtz type equipment that generated rectangular voltage pulses. The results showed that fewer roots grew in the specimens exposed to pulsed MF (14±6 roots on day 1 to 21±8 on day 4) than in the control groups (32±17 to 48±23) (p<0.05 Friedman). Control specimens showed a root mean length of 7±4 mm (day 1) and 24±10 mm (day 4). The specimens treated with pulsed MF showed a length of 4±2 mm (day 1), reaching 18±9 mm on day 4 (p<0.001 ANOVA). In conclusion, the exposure of *Allium cepa* specimens to 25Hz, 1.5mT pulsed MF during 33h produces a decrease in the germination and growth of roots.

KEYWORDS: Pulsed magnetic field; *Allium cepa*; growth; root; plant.

Introduction

Plant growth depends on a variety of environmental factors, including light, temperature, water and nutrients (Bechtold and Field, 2018). However, other non-biological factors such as electric field, radioactivity, earthquakes, geothermal, gravitation, geochemistry and magnetic fields (MF), represent not only important stressors but also unavoidable conditions during plant growth (Belyavskaya, 2004; Nyakane et al., 2019).

In animals and plants, the perception mechanism of the Earth's magnetic field is not yet fully understood. MF is an unavoidable environmental factor for all living organisms and affects many biological processes. In recent years, the effects of MF on plants have been thoroughly studied and the results have shown that there are still uncharacterized plant magnetoreceptors (Phirke et al., 1996; Abe et al., 1997; Belyavskaya, 2004; Minorsky, 2007; Teixeira da Silva and Dobránszki, 2015, 2016; Agliassa et al., 2018b).

Recently, it was found that reducing MF to near a null value (NVMF) affects the nutritional status of plants. In fact, under NVMF conditions, the content of necessary inorganic cations and anions and the gene expression of their conveyors and channels are affected. In addition to these ions, other elements (such as iron, copper, zinc and manganese) are also essential for plant growth (Palmer and Guerinot, 2009; Marschner, 2011; Vigani and Murgia, 2018). Deciphering the effects of MF and other geophysical fields on plants is a challenge because it is difficult to achieve specific experimental conditions (Hoson, 2014). One way to test the effect of MF on plants is to expose plants in conditions where MF changes by increasing or decreasing MF flow. This condition can be achieved using a MF compensation system (Bertea et al., 2015; Agliassa et al., 2018a).

The study carried out by Islam et al. (2020) evaluating the effect of MF on the absorption of metals by *Arabidopsis* seedlings by comparing plants grown under MF or NVMF condition showed that plants exposed to NVMF show iron deficiency-induced responses and a decrease in root faith reductase activity, demonstrating the key role of natural MF for metal absorption.

With the availability and popularity of devices that emit radiofrequency radiation (RF), such as mobile phones, public attention has been caught about the potential adverse health effects of exposure to this type of radiation (Velizarov et al., 1999; Trosic et al., 2002; Busljeta et al., 2004). The possible genotoxic effects of RF exposure in various biological systems have been studied (Verschaeve and Maes, 1998; Vijayalaxmi and Obe, 2004; Verschaeve, 2005). Among them, the *Allium* test is one of the most comprehensive testing systems; due to its sensitivity and good correlation with animal testing systems, it has been used routinely (Fiskesjo, 1985; Fiskesjo, 1993; Panda and Panda, 2002). The onion test shows that onion bulbs germinate, but roots can also be obtained by germinating seeds for analysis (Leme and Marin-Morales, 2008). Tkalec et al. (2009) did not observed changes in germination rate and root length but an important increase in mitotic index and mitotic abnormalities after exposure to 400 and 900 MHz, 4 h exposure of *Allium cepa*. These authors conclude that the effects depend on the field frequency and strength. Recently, Kumar et al. (2020) reported a decrease about 13% in root length and an increased chromosomal aberration index up to 266% after 4h exposure to 1800 MHz.

Most of the recently published papers exposing different organisms (seeds, plants, algae) use static MF in different conditions. Some studies were carried out with high static fields, from 100 to 600 mT, and others with much lower levels, from 3 to 90 mT, are noteworthy. They all have in common that the MF produced stimulating effects, such as increase in root length after 600 mT exposure (Jin et al. 2019); 94 % increase in dry mass (after 200 mT) (Mohammadi and Roshandel, 2020); improve seeds germination, length and biomass of plants and increase plant growth and photosynthesis (after 150-250 mT) (Radhakrishnan, 2019); increase of growth and oxygen production (after 100 mT) (Tu et al. 2015); increment of growth, seed germination rate, root and shoot length and biomass weight (after 7 mT) (Shabrangy et al. 2021) or increase of seeds germination (after 4-20 mT and 50-332 mT) (Sarraf et al. 2020). Wang et al. (2008) reported that the observed effects depends on magnetic flux density. Theses authors observed an increment of superoxide dismutase and peroxidase activities (after 10-35 mT of exposure), a catalase activity

increase (after 45-50 mT) and also a growth rate increment after 72 h. of *Chlorella vulgaris* cultivation exposed to 10-35 mT.

Fewer studies have been published using variable frequency magnetic fields, both sinusoidal and pulsed. Liang et al. (2004) reported an increase of inactivation and killing of cells with a 94 % of mortality in 6 minutes after exposure of algae cells to a pulsed MF with varying frequency. In addition, Sukhov et al. (2021) reported a decreased yield of photosystem II after short-term treatment with sinusoidal MF (18 μ T; 7.8, 14.3 and 20.8 Hz) in different plants species. Moreover, Radhakrishnan (2019) observed a decrease in: lipid peroxidation, catalase activity, Ca content, alpha-amylase, alkaline phosphatase, protease, and nitrate reductase activity; after pulsed MF exposures of *Glycine max* L. to 1.5 μ T, 1 and 10 Hz. In contrast, Radhakrishnan and Kumari, (2012) observed an increase of plant height, fresh and dry weight increment and also higher number of leaves, pods, and length of pods, in *Glycine max* L., exposed to pulsed MF (1.5 μ T, 10 Hz, 5h/day). Also, Baldev et al. (2021) showed a 25 % increase in biomass production and active oxygen production in *Chlorella vulgaris* exposed at 0.07 mT, 1 Hz, 4h/day.

Because there are very few published works on the effects of variable magnetic fields and the results observed to date show contradictory data, both for stimulatory and inhibitory effects; it is necessary to contribute with new studies in order to elucidate the effects of pulsed MF of low intensity and frequency. It is important to know these effects in order to elucidate the action mechanisms and the possible dose-response relationships with the ultimate goal of obtaining better crop growth yields. Very few studies on plants, which investigate the effects of pulsed MF with frequencies below 50/60 Hz, have been reported. In this way, the aim of this work is to study the effects of 25 Hz, 1.5 mT pulsed MF exposure on the germination and growth of *Allium cepa* L. roots.

Materials and methods

Biological model

Specimens of *Allium cepa* L. of the commercial variety of Spanish yellow onion or common onion were used as a study model. Onion bulbs were obtained from the local market. Bulbs of equal size (57.13 ± 10.09 g) were washed with distilled water.

Magnetic field exposure system

To generate pulsed MF, we used the equipment previously described by Ruiz-Gómez et al (2002) and Ruiz-Gómez and Martínez-Morillo (2005). This equipment (helmholtz type) consists of 2 air core coils connected in series (15cm x 10.5cm) that generated 25 Hz rectangular voltage pulses (Pulsatrón—CEM-84/J, J.&J. Electromédica, Málaga-Spain). The number of windings making each coil is not known because the manufacturer has not report this information. Furthermore, it is not feasible to open the applicator that contains the coil because it contributes to its destruction and rendering it unusable for its use in magnetotherapy.

The waveform of the voltage applied at 25Hz consisted in groups of 15 square pulses (180 μ s width, 20 μ s gap) of 1.5mT peak (uniformity $\pm 5\%$ as calibrated by the manufacturer). There were 25 temporally equally-spaced wave-trains per second (Fig. 1).

The value of the low-frequency MF associated with the voltage waveform is proportional to the level of current intensity in a circuit (Law of Biot-Savart) and its time derivative has the same waveform as the electromotive force in a pickup coil in air (Faraday's Law of electromagnetic induction). The waveform of the time derivative of the current intensity in the circuit (the same waveform as the time derivative of the MF) was measured with a pickup coil in air, being tested that it was according to the temporal variation of the current intensity in an inductive circuit.

According to Faraday's Law of Induction, a time varying MF will induce an electric field according to the equation:

$$\xi = \oint_c \vec{E} \cdot d\vec{l} = - \frac{d}{dt} \iint \vec{B} \cdot d\vec{S}$$

ξ = induced electromotive force (V), E = electric field (V/m) and B = magnetic field (T).

Considering a circular contour (c) of radius r, coaxial with the coils and parallel to them, this equation (in an homogeneous MF in the surface (S) inside the contour) becomes:

$$\xi = E \cdot 2\pi r = -\pi r^2 \frac{d}{dt} B$$

At low frequencies, the MF is proportional to the intensity that flows through the coils (Biot-Savart law) and hence dB/dt is proportional to di/dt . The ξ waveform was observed and measured in an oscilloscope, for 3 different radii, using a circular pickup coil in air between coils. Qualitatively it corresponds with the waveform obtained for di/dt in a R-L circuit, such as it was in our case. The ξ waveform consisted of pulses decreasing exponentially towards zero volts, positive in those intervals, in figure 1, corresponding to 180 μ s and negative in those of 20 μ s. After the measurements of ξ pulses, the corresponding peak values of the electric field were calculated using the expression:

$$E = \frac{\xi}{2\pi r}$$

The measurements were made with pickup coils of radii 2, 3, and 4 cm. The obtained values were: 0.5, 0.7, and 0.8 V/m for the positive pulses and 2.98, 3.82 and 3.98 V/m for the negative ones, respectively.

The onions were exposed 8h and 15min per day during 4 days. The total exposure period was 33h. The equipment was used at its maximum potency generating a magnetic flux density similar to the values used by other authors (Li and Chow, 2001). The equipment used is commercially

manufactured for magnetotherapy treatment in rehabilitation clinics. By this reason, the frequency and the magnetic flux density are limited to the maximum value of 25 Hz, 1.5mT peak. Therefore, there is no possibility to increase the value of these parameters. Figure 2a shows a photography of this equipment.

Background magnetic field

The DC geomagnetic field in Málaga is 42.95 μ T (27.225 μ T horizontal, 33.20 μ T vertical; 3°5' Western (Data from the Institute of National Geographic, Madrid, Spain). The background MF in the laboratory was 0.68 μ T (López-Díaz et al., 2014).

Exposure protocol

Four onion bulbs were placed in glasses with water allowing it to be dipped only 0.5 cm from their basal end in distilled water. This set was placed between two solenoids at room temperature away from external sources of artificial magnetic fields. The magnetic field distribution ran perpendicular to the growth axis of the roots (Fig. 2b and 2c). The polarity of the magnetic field (north to south) to which the plants were exposed was 90° perpendicular to the gravity vector of root growth. Pulsed MF-treated specimens and the corresponding controls experienced the same sequence of manipulation and temporal coincidence of treatment. Exposures were performed at 23°C (measured by a conventional thermometer). A standard fan was used to dissipate the heat produced in the coils. Other four control bulbs were placed 5 m apart from the coils in the same environmental conditions. There was no additional heating due to the activation of the coils, as measured directly by a conventional thermometer. The onions showed no roots at the beginning of the experiments.

Roots growth and weigh measurement

Each day during the exposure period, the number of roots that each onion specimen had was counted. The growth of the roots was carried out by measuring their length each day with a conventional ruler. Fresh weight was measured at the end of the exposure period after cutting the roots and weighing them on a conventional scale.

Statistical Analyses

The Wilk-Shapiro rankit-plot test was used to assess the normal distribution of the data. Additional statistical analyses were made with the Student's *t*-test, Analysis of Variance (ANOVA) or Friedman as appropriate. Differences were considered significant when $p < 0.05$.

Three independent experiments in quadruplicate were performed (n=12 for control and n=12 for treatment).

Additional review of recent published papers (2019-2021)

To enhance the quality of this paper, a PubMed search was performed using the keywords "magnetic field, plant, algae, *Allium*, and growth". Articles related to effects of different MF (pulsed, sinusoidal, static, and radiofrequency) of low and high magnetic flux density from 2019 to 2021 were analyzed. Articles which combine the effects of MF with other physical or chemical agents were excluded.

Results and discussion

This study was carried out by exposing specimens to a pulsed MF during 4 days. The distribution of the mean weight of the specimens used was 52.63 ± 11.53 g for the control group and 61.63 ± 6.23 g for the group exposed to pulsed MF (Fig. 3). There were no significant statistical differences between onions exposed in both groups at the beginning of the experiments. Therefore, in both groups the size of onions was similar.

At the beginning of the tests, the onions did not present any roots. Once the exposure period was over, all the roots were cut and weighed, obtaining mean values of fresh weight of 0.269 ± 0.134 g for the control group and 0.199 ± 0.090 g for the group treated with pulsed MF (Fig. 4). The differences between both groups were not statistically significant ($p > 0.05$ Student's *t*-test).

However, the study of the number of roots grown during the exposure period showed that fewer roots grew in the specimens exposed to pulsed MF than in the control groups. As can be seen in figure 5, the control group showed 32 ± 17 roots on the first day, increasing their number until reaching 48 ± 23 roots on day 4. On the contrary, the group treated with pulsed MF showed 14 ± 6 roots on the first day with a slight increase during the 4 days of exposure until reaching 21 ± 8 roots. The differences between both groups were statistically significant ($p < 0.05$ Friedman). Furthermore, the length of the roots measured during the exposure period also showed statistically significant differences ($p < 0.001$ ANOVA). The roots of the control specimens showed a mean length of 7 ± 4 mm on day 1, which increased reaching a mean length of 24 ± 10 mm on day 4. The specimens treated with pulsed MF showed a length of 4 ± 2 mm on day 1, reaching 18 ± 9 mm on day 4 (Fig. 6).

The magnetic field is an unavoidable environmental factor for all living things. It may have positive or negative effects depending on factors such as intensity or exposure time. Experiments conducted on *Allium cepa* demonstrate the MF ability to produce effects on living things. Individuals undergoing radiation showed a number of differences with respect to control individuals; weight, root's weight, number of roots and root's length, being significantly different

the number of roots and their length. As described above, radiation can cause a decrease in the absorption of micronutrients needed for plant development such as iron, zinc, copper or magnesium (Palmer and Guerinot, 2009; Marschner, 2011; Vigani and Murgia, 2018). This deficit results in significant differences in both models. Moreover, other researchers have shown that these parameters and others such as weight or cellular division capacity may be affected by long exposure to the magnetic field. Pulsed MF have been reported to induce genomic DNA damage in yeast cells. Among the proposed mechanisms of action, the increase in free radicals produced by the MF applied (Reactive Oxygen Species, ROS) could damage different cell structures, especially the DNA (Mercado-Sáenz et al., 2019, 2021). However, this aspect of magnetic biology still deserves an in-depth study as well as its possible genotoxic side effects (Sarraf et al., 2020). Another explanation of the observed effect could be that plants are adapted to grow under the continuous action of the earth MF exposure but not under the effect of the artificial pulsed MF (discontinuous) used in this study.

Nevertheless, several studies have shown that to improve seed germination and increase crop productivity and development, the right combination of MF intensity and exposure time is essential. Many studies have shown that its positive effects can improve seed germination, root and stem length, water and CO₂ absorption, photosynthetic pigment content and ultimately increase agricultural yields even under abiotic stress.

The additional review performed with recently reported articles from other authors (between 2019-2021) to enrich the manuscript and compare with the results found show different effects of MF exposure in different model organism. In this regard, it is noteworthy that the majority of articles show a stimulating effect in different species exposed to static MF, both with low and high magnetic flux density. As shown in table 1, Jin et al. (2019) found a high stimulation of root length with more active cell division in the meristem when MF is applied parallel to growth (North to South) and less stimulation when MF was 90° perpendicular to the gravity vector. No effect in the opposite direction to growth (South to North) in *Arabidopsis thaliana* exposed to 600 mT static MF was reported by them. In our case, the direction of the MF was also 90° perpendicular

to the grow of roots which could influence the results. In addition, other authors found an increase of seed germination using static MF in the ranges of 4-20 mT, 50-332 mT and 150-250 mT, (Radhakrishnan, 2019; Sarraf et al. 2020) and an improve of crop growth and yield of sunflower after exposures of seeds to 100 and 200 mT (Afzal et al. 2021; Vashisth et al. 2021). These authors did not find stimulating effects at 50 or 150 mT, during 5, 10 or 15 minutes of exposure. The exposure of seeds to static MF (150-250 mT) has produced more vigorous plants with higher length and biomass by increasing plant growth and photosynthesis (Radhakrishnan, 2019). In addition, low magnetic flux densities (7 mT, 6 h/day, 5 days) also produced an increase of plant growth, root and shoot length and biomass weight (Shabrangy et al. 2021). These effect has been observed also in plants at higher static MF values (100 mT, 3 days; 30-150 mT, 20 min./day) (Yang et al. 2021). At cellular level, the exposure of unicellular algae to static MF (20, 25, 30 and 60 mT) also induced the increment of growth (Sarraf et al. 2020). However, some authors did not find stimulatory effects at all assayed values of magnetic flux densities. Mohammadi and Roshandel (2020) observed a 94 % increase in dry mass, chlorophyll and polyphenol and a 92 % increase in catalase activity and 2.3-fold increase in ascorbate peroxidase activity after exposure to 200 and 250 mT, 5 min.; but they observed no effect at 45 and 90 mT. Negative effects of exposure to a static MF (2.9-4.7 mT) have even been described. In this way, Radhakrishnan (2019) reported a decrease of superoxide dismutase, catalase, peroxidase and ascorbate peroxidase activities.

In relation to other type of MF (pulsed, sinusoidal and radiofrequency), the contradictory effects are evident. De Souza-Torres et al. (2020) reported an improve of vegetative growth of plants exposed to sinusoidal MF, non-uniform (120 mT, 10 min.; 80 mT, 5 min.); and Baldev et al. (2021) observed a 2-fold increase in algae biomass production at 0.07 mT, pulsed MF, 1 Hz, 4h/day. However, Kumar et al. (2020) found a root length decrease about 13% at 900 MHz, 4 h.; and an increased index of chromosomal aberration (41%-266%) after 4 h exposure to 900 and 1800 MHz, with cytotoxic and DNA damage induction in root meristems. It is logical to think that a higher frequency produces a greater deposit of energy and therefore cell damage can be

triggered. However, the inhibitory effect has also been observed in exposures with a static MF, previously described, and with a sinusoidal and pulsed MF. Regarding the latter, Radhakrishnan (2019) described a decrease in lipid peroxidation and catalase activity at only 1.5 μ T, 1 Hz, pulsed MF; and a decrease of Ca content, alpha-amylase, alkaline phosphatase, protease, and nitrate reductase activity at 1.5 μ T, 10 Hz, pulsed MF). Recently, Sukhov et al. (2021) reported a decreased non-photochemical quenching and influenced quantum yields of photosystem II at short-term treatment of plants with sinusoidal MF (18 μ T; 7.8, 14.3 and 20.8 Hz). They affirm that MF could influence the photosynthetic light processes that depends on plant species and type of treatment. The exposure times used in the studies reported are variable from 5 minutes to 5 days. In addition, the model organism were different plants, algae and seeds (Table 1). All this work highlights the need for more research to expand our knowledge about MF effects.

Our results coincide with those described in the literature in relation to the fact that exposure to pulsed MF of low intensity and frequency produces an inhibitory effect. The direction of the MF (90° perpendicular to the gravity vector) in relation to the growth of roots could influence this effect. Plants, adapted to grow under the geomagnetic field, could be altered by other type of artificial MF such as sinusoidal or pulsed MF at low frequencies and intensities and even static MF of higher magnetic flux densities, as described.

Conclusion

As it has been described, the effects of the MF depend on the field type (static, sinusoidal, pulsed), the magnetic flux density, the frequency and the exposure time. In addition, these effects vary in different organisms. This fact is reinforced by the opposite effects observed by different authors, in different plants, algae and seeds exposed to static, sinusoidal, pulsed and radiofrequency MF of low and high intensity and frequency. It is logical to think that the growth of the roots in a plant is adapted to terrestrial geomagnetism, in such a way that the exposure to artificial MF, to which

the plants are not adapted, could produce alterations in the growth pattern. In this sense, the pulsed MF used in this study could act as a damaging agent or an inhibitory of geotropism agent. Our study shows that fewer roots grew in the onions exposed to pulsed MF (14 ± 6 roots on day 1 to 21 ± 8 on day 4) than in the control groups (32 ± 17 to 48 ± 23). In addition, the length of the roots in onions treated with pulsed MF was shorter (4 ± 2 mm, day 1; 18 ± 9 mm, day 4) than in the control onions (7 ± 4 mm, day 1; 24 ± 10 mm, day 4). In conclusion, the exposure of *Allium cepa* L. specimens to 25 Hz, 1.5 mT pulsed MF during 33 h produces a decrease in the germination and growth of roots.

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FIGURE LEGENDS

Figure 1. Tension waveform generated by the Pulsatrón—CEM-84/J equipment. The number of rectangular pulses (180 ms) was 15 at 25 Hz. The magnetic field generated by the coils has the same waveform with the time.

Figure 2. Magnetic field exposure system. a) Photography of the Pulsatrón—CEM-84/J equipment that generates pulsed magnetic field. b) Diagram of the equipment and location of specimens. Onions were located on glasses with water between solenoids. The magnetic field distribution ran perpendicular to the growth axis of the roots. b) Cross section.

Figure 3. Weight of the onion specimens used in the experiments. Mean±SD. PMF: pulsed magnetic field. The size of onions used in the assays was similar in both groups. $p>0.05$ Student's *t*-test.

Figure 4. Fresh weight of all roots grown measured at the end of the exposure period. Mean±SD. PMF: pulsed magnetic field. $p>0.05$ Student's *t*-test.

Figure 5. Number of roots grown during the exposure period. Mean±SD. PMF: pulsed magnetic field. $p<0.05$ Friedman.

Figure 6. Length of roots grown during the exposure period. Mean±SD. PMF: pulsed magnetic field. $p<0.001$ ANOVA.

Table 1. Summary of recent studies of MF treatment on different organisms and their response.

MF exposure	Organism	Induced changes	Reference
Pulsed MF (0.06-0.09 mT)	<i>Chlorella vulgaris</i>	25 % increase in biomass production and active oxygen. 2-fold increase in biomass at 0.07 mT, 1 Hz, 4h/day	Baldev et al. 2021
Pulsed MF (1.5 μ T, 1 and 10 Hz)	<i>Glycine max</i> L.	Decrease lipid peroxidation and catalase activity (1 Hz). Decrease of Ca content, alpha-amylase, alkaline phosphatase, protease, and nitrate reductase activity (10 Hz)	Radhakrishnan, 2019
Sinusoidal MF, non-uniform (120 mT, 10 min.; 80 mT, 5 min.)	<i>Solanum lycopersicum</i>	Improve vegetative growth of plants	De Souza-Torres et al. 2020
Sinusoidal MF (18 μ T; 7.8, 14.3 and 20.8 Hz)	<i>Triticum aestivum</i> L., <i>Pisum sativum</i> L.	Decreased non-photochemical quenching and influenced quantum yields of photosystem II at short-term treatment. MF could influence the photosynthetic light processes that depends on plant species and type of treatment	Sukhov et al. 2021
Static MF (600 mT)	<i>Arabidopsis thaliana</i>	Stimulation of root length with more active cell division in the meristem when MF is applied parallel to growth (North to South) and 90° perpendicular to the gravity vector. No effect in opposite direction to growth (South to North)	Jin et al. 2019
Static MF (200 mT, 2 h.)	<i>Helianthus sp.</i> L.	Exposure of seeds improve growth and yield of sunflower	Vashisth et al. 2021
Static MF (45, 90, 200, and 250 mT; 5 min.)	<i>Hyssopus officinalis</i> L.	94 % increase in dry mass, chlorophyll and polyphenol. 92 % increase in catalase activity and 2.3-fold increase in ascorbate peroxidase activity. No effect at 45 and 90 mT	Mohammadi and Roshandel, 2020
Static MF (100 mT, 3 days; 30-150 mT, 20 min./day)	<i>Celosea argentea</i>	Increase biomass production of roots and leaves after exposure of seeds	Yang et al. 2021
Static MF (50, 100, 150 mT; 5, 10, 15 min.)	<i>Helianthus annuus</i> L.	Improve emergence, crop growth rate and sunflower yield after expose seeds to 100 mT, 10 min. No effect at the other MF conditions of exposure	Afzal et al. 2021
Static MF (150-250 mT)	Multiple plants	Improve seeds germination, length and biomass of plants. Increase plant growth and photosynthesis	Radhakrishnan, 2019
Static MF (around 100 mT; range 4-20 mT and 50-332 mT)	Multiple	Increase seed germination	Sarraf et al. 2020
Static MF (20, 25, 30 and 60 mT)	Algae	Increment of growth	Sarraf et al. 2020
Static MF (7 mT, 6 h/day, 5 days)	<i>Hordeum vulgare</i> L.	Increment of growth, seed germination rate, root and shoot length and biomass weight	Shabrangy et al. 2021
Static MF (2.9-4.7 mT)	<i>Triticum aestivum</i> L.	Decrease of superoxide dismutase, catalase, peroxidase and ascorbate peroxidase activities	Radhakrishnan, 2019
Radiofrequency MF (900-1800 MHz, 0.5-4 h.)	<i>Allium cepa</i> L.	Root length decrease about 13% at 900 MHz, 4h. Chromosomal aberration index increased (41%-266%) after 4h exposure to 900 and 1800 MHz. Cytotoxic and DNA damage induction in root meristems	Kumar et al. 2020

MF: Magnetic field

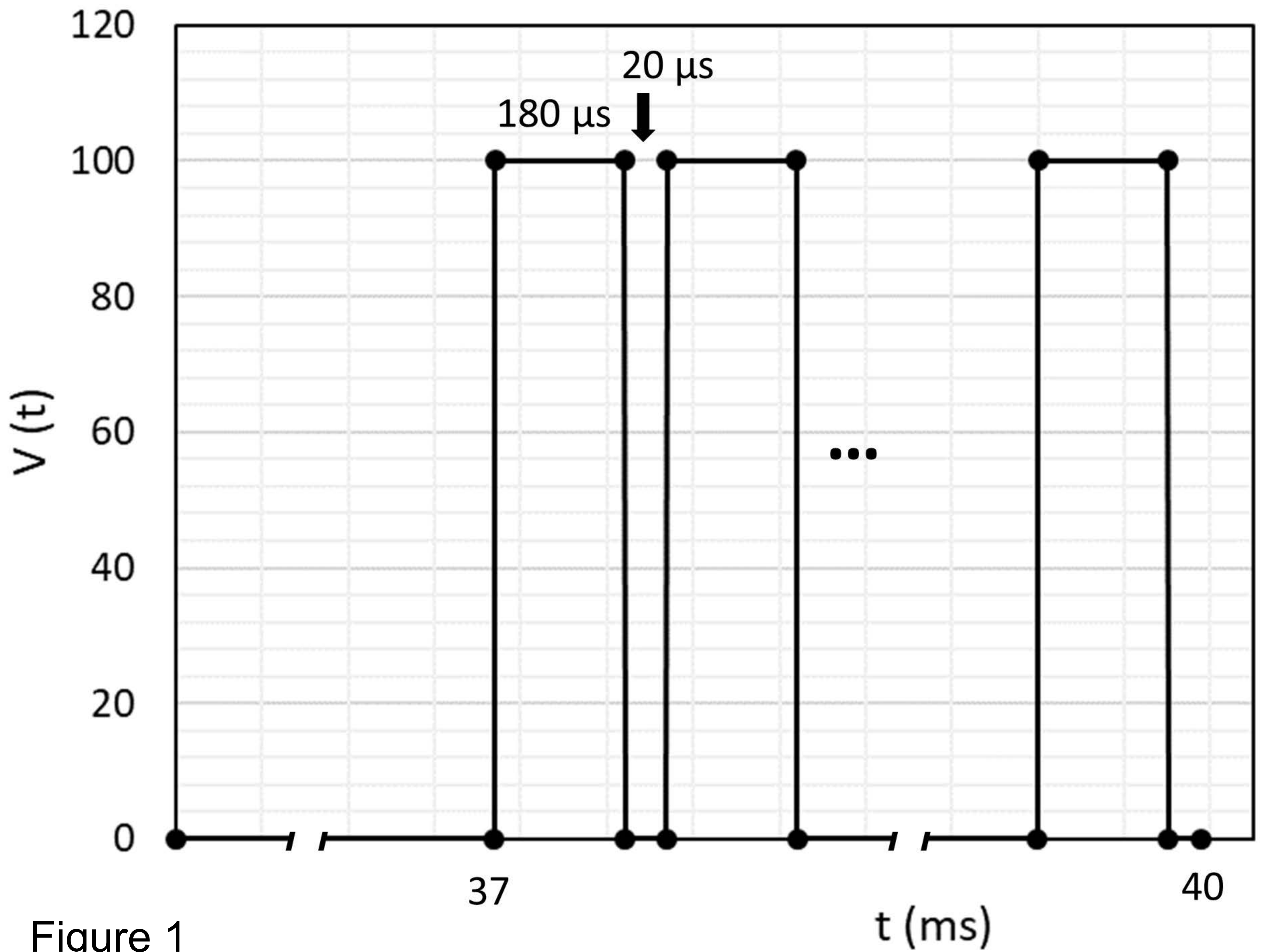


Figure 1

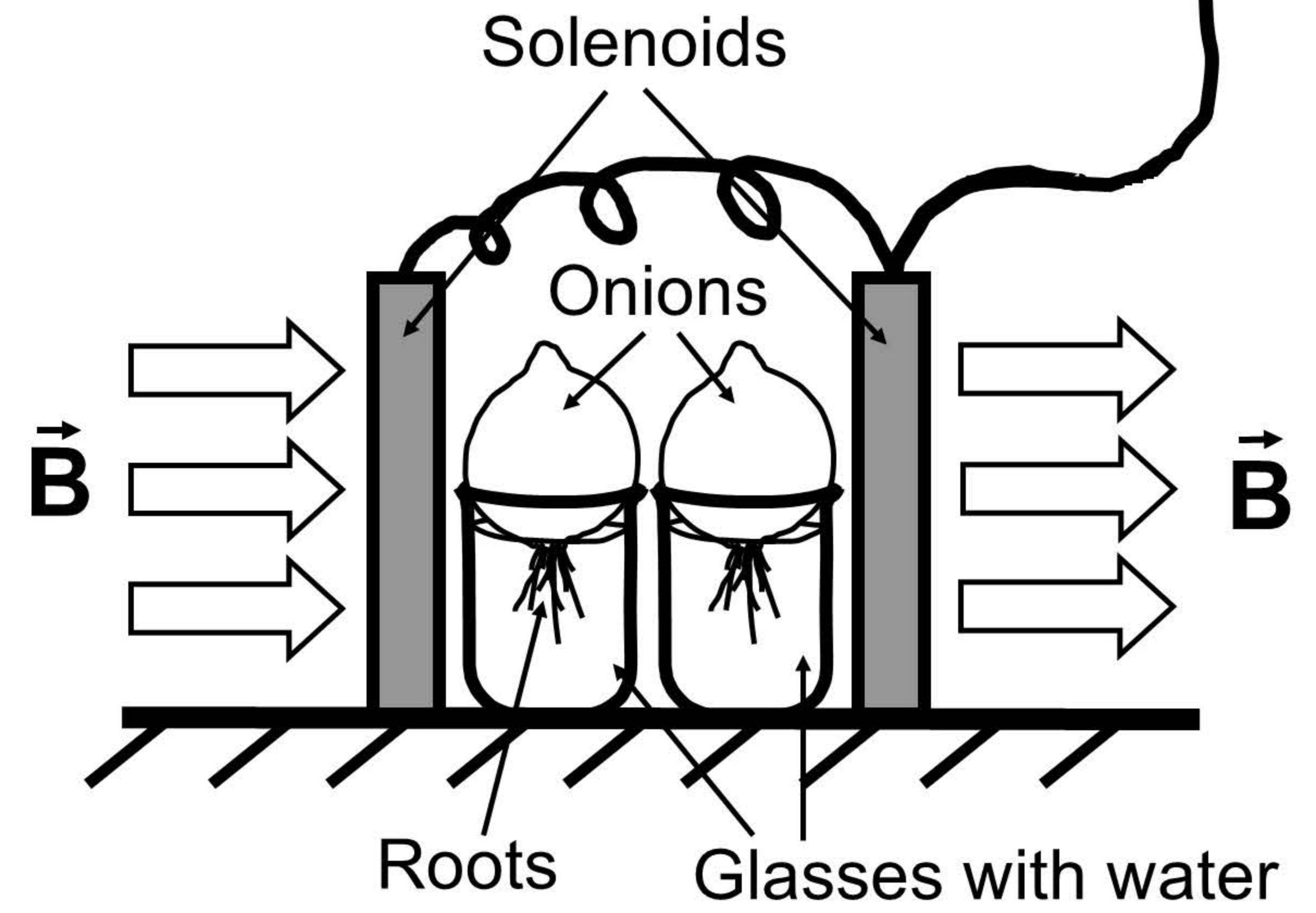
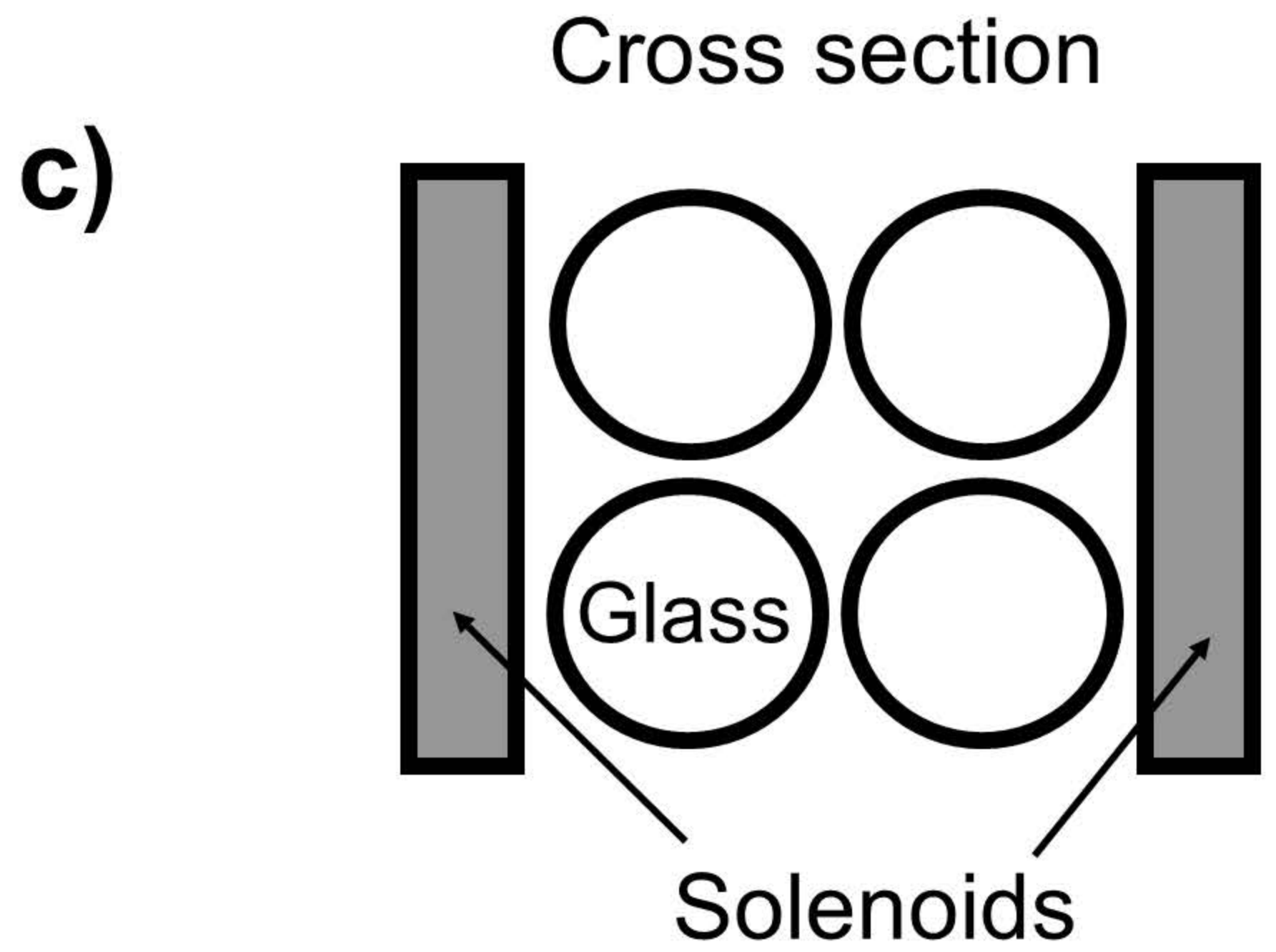
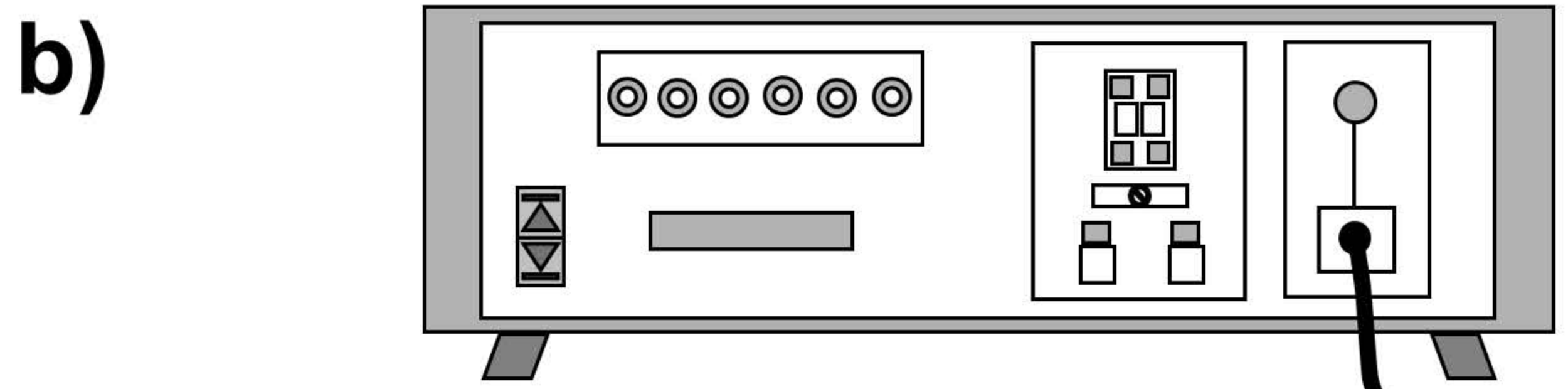


Figure 2

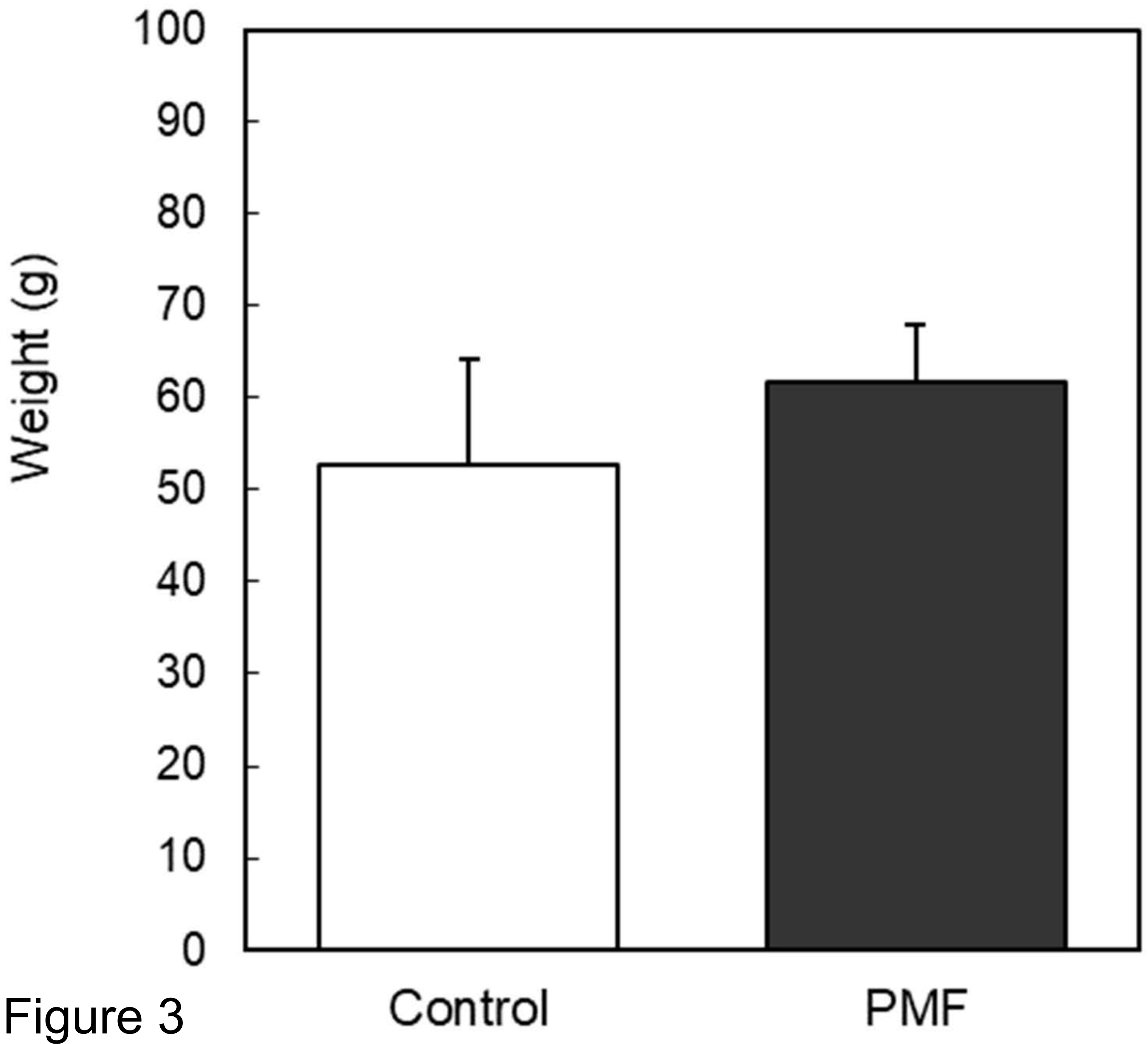


Figure 3

Root fresh weight (g)

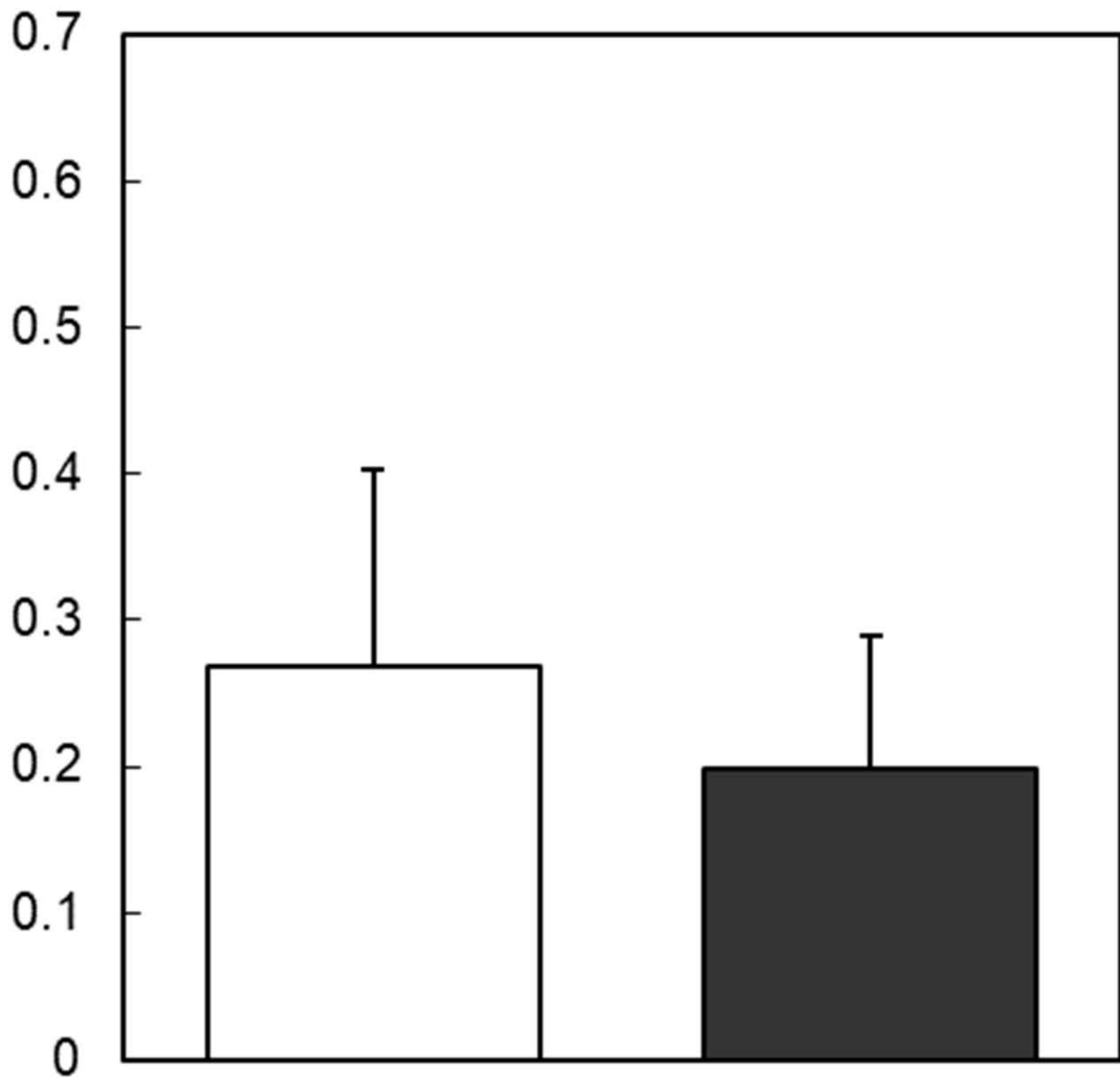


Figure 4

Control

PMF

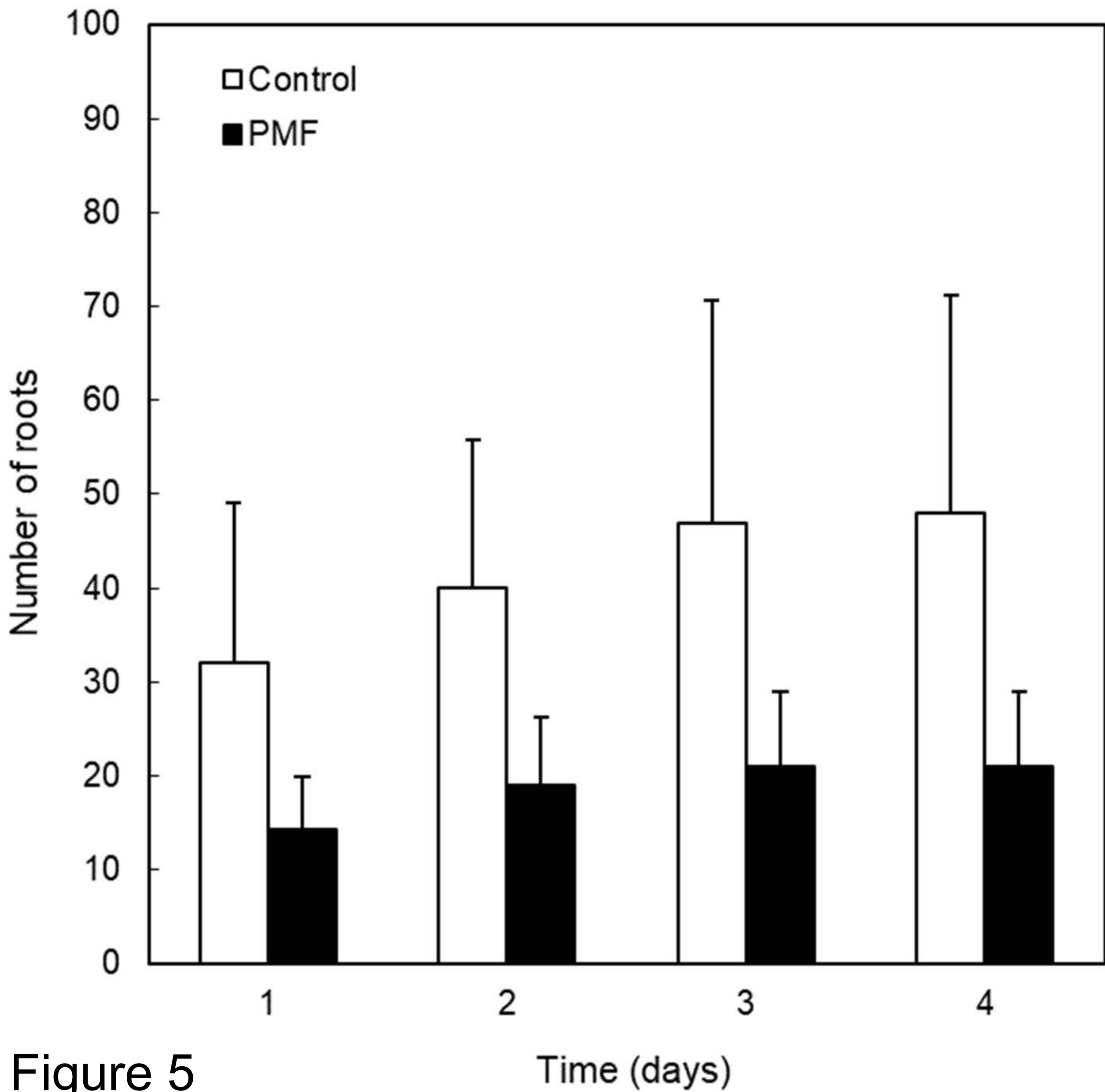


Figure 5

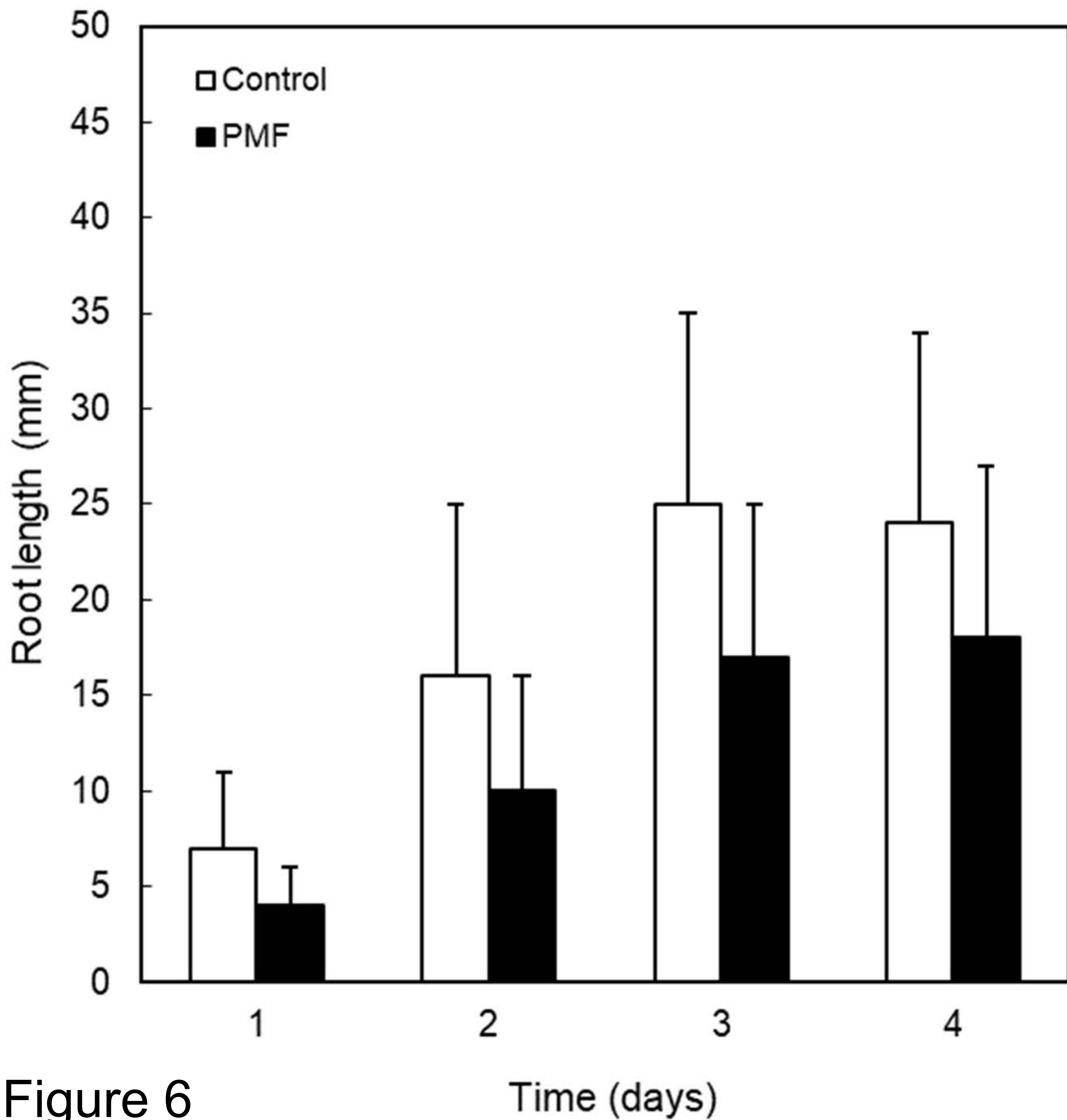


Figure 6