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Exposure to electromagnetic fields used in precision agriculture do not affect redox status in maize

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Abstract

Nowadays many technologies aid farming efficiency – practice called precision agriculture. Wireless sensors collecting environmental data increase electromagnetic field levels in the farmland. The aim of this study was to investigate the possible effects of 900 MHz electromagnetic field used in precision agriculture on the redox status in maize. *Zea mays* variety Knezha-683A plants were grown in pots under controlled laboratory conditions until development of the second leaf. Then the pot was exposed to 900 MHz electromagnetic field in an anechoic chamber for 2 hours (marked as *EMF*). The antenna was located sideward of the plants, so the electric field vector (370 V/m) was parallel to the stems. Since the plants located along the pot edges are expected to absorb more electromagnetic energy than the plants in the center, they were considered as separate experimental groups: *Outer* – closer to the antenna, and *Inner* – further from it. The second pot was transported to the place of irradiation but the plants were not exposed to the electromagnetic field – *control*. The third pot was kept in the growth chamber – *referent control*. After exposure, the hydrogen peroxide content and total antioxidant activity in the second leaf were measured. The presented data were averaged from six independent experiments. Our results show there was no statistically significant differences in the hydrogen peroxide content and the total antioxidant activity between the exposed and control maize variants, as well as between *Inner* and *Outer* plants. Under the investigated exposure conditions 900 MHz electromagnetic field did not induce alterations in the redox status in young maize plants.

***Keywords**:* 900 MHz electromagnetic field, hydrogen peroxide, total antioxidant activity

INTRODUCTION

Nowadays wireless communication technologies are used in farming – so called precision agriculture. Different sensors are located in the farmland, sending information about environmental conditions as to a control device using radiofrequency (RF) electromagnetic signals. Sensors can be placed at different depths in the soil, on the surface, or attached to the plants. The information that various sensors can provide is related to meteorological conditions (temperature and relative air humidity, wind speed and direction, dew point, solar radiation, atmospheric pressure) Additionally, data about air quality, temperature (at different depths), humidity, pH and soil composition (nitrogen, carbon and organic matter) can be collected. Furthermore, data about water content, amount of chlorophyll in the leaves, loading and density of the soil and its mechanical resistance can be available. Various sensors also can monitor the effects of agricultural machinery, air permeability of the soil and so on (Rajak *et al.*, 2023). Based on the data from the sensors, located and mapped with

GPS systems and drones, specific areas which need a certain amount of water, fertilization, pesticides, weeding can be determined. This increases the farming effectiveness but also increases the electromagnetic field (EMF) background for the plants and other field inhabitants.

Parameters of the applied EMFs, such as frequency, power density and electric field, as well as time duration of exposure, are factors that influence the growth and development of green plants (Panda *et al.*, 2024). Any change in the external conditions, including EMF background, causes a reaction in the plant which is often associated with disturbance of redox homeostasis (Chandel *et al.*, 2017, Kaur *et al.*, 2021). RF EMF do not have sufficient quantum energy to induce ROS formation. However, they can alter the activity of antioxidant enzymes, thereby causing an imbalance in the processes of free radical production and scavenging. Indicators of oxidative stress are among the most sensitive parameters, and are often studied to assess the influence of various factors on plants.

Our hypothesis is that, because the irradiation of the plants is uneven across the field, they might be influenced to varying degrees. Plants located in close proximity of the sensors absorb more of the emitted EM energy than those farther away. The reactions of biological systems to EMF depend on the amount of energy absorbed. Since 900 MHz EMF are used in precision agriculture, the aim of the current study was to investigate their effects on the redox status of maize plants, and to determine where there is difference in the reactions of plants exposed to the RF EMF compared to those which screened behind them.

MATERIALS AND METHODS

The plant material and the growing conditions have already been described (Kouzmanova *et al.*, 2024). *Zea mays* variety Knezha-683A (Maize Research Institute, Knezha, Bulgaria) seeds were sown in three pots, in a universal peat-soil mixture, pH 6.5 (Gamma Company Ltd., Sofia, Bulgaria), 17 seeds per pot. The plants were grown in a chamber under controlled conditions: 23/25°C night/day, 80 μmol photons/(s.m^2) PPFD (Photosynthetic Photon Flux Density) and 12/12 h light/dark photoregime.

EMF treatment was applied when plants developed their second leaf (10 days after sowing). The exposure setup is described in Kouzmanova *et al.* (2024). In short: one of the pots was exposed to 900 MHz continuous wave *EMF* in a semi-anechoic chamber for 2 hours. The antenna was located sideward of the pot so the electric field (E) vector was parallel to the stems. To ensure homogeneous exposure of plants, the pot was placed on a rotating table. However, even in that setting the plants located in the center of the pot were farther from the antenna and were screened by the plants located along the pot edges. Since that disparity should result in different EMF doses absorbed by the two plant groups, they were labeled as *Outer* (closer to the antenna) and *Inner* (farther from the antenna), and position in the pot was considered an independent experimental factor. The electric field at the spot of the pot was 370 V/m. The second pot – *control*, was transported to the place of irradiation but the plants were not exposed to the EMF. The third pot stayed in the growth chamber – *referent control* (*RC*).

Redox status was evaluated by the hydrogen peroxide (H_2O_2) content and total antioxidant activity (TAA) in the second leaf at two time points – one and two hours after exposure. At each time point approximately 300 mg leaf material (fresh weight, FW) was collected from 3 plants, chosen randomly from each pot (about 100 mg per plant), homogenized with quartz sand by mortar and pestle in 3 mL 1% w/v trichloroacetic acid (TCA) at 4°C, and proceeded according to method of Alexieva *et al.* (2001). TAA was determined by the ABTS radical cation decolourization assay (Re *et al.*

1999). Both methods are described in detail by Kouzmanova *et al.* (2024).

The presented data are: average ± SEM (standard error of mean) values calculated from six separate repetitions. Two-way ANOVA, with factors: position in pot (*Inner* and *Outer*) and combination treatment–time-interval-after-treatment (*Control - 1 h*, *Control - 2 h*, *EMF - 1 h*, *EMF - 2 h*, *RC - 1 h* and *RC - 2 h*), followed by Tukey's HSD (honestly significant difference) test were applied to determine statistically significant differences between experimental variants (α = 0.05). Pearson correlation coefficient (ρ) between experimental values of H_2O_2 and TAA was calculated (n = 144). All statistical analyses as well as the presented graphics were made by R programme (link).

RESULTS AND DISCUSSION

The H_2O_2 content across all the experimental variants is shown on Figure 1. Neither treatment, nor pot position affect the level of H_2O_2 fluctuating around 24 nmol/g FW. It does not change in time as well, despite some minor deviations across periods for plants in *Outer* position. Similarly to the H_2O_2, the antioxidant activity did not depend on any of the factors examined in the study (Fig. 2). Moreover, correlation between both parameters was positive, but weak (p=0.25).

In our previous experiment we had investigated the possible effect of the electric field polarization (horizontal and vertical) on the oxidative stress of maize plants (manuscript under review). The applied experimental conditions were the same – 900 MHz electromagnetic wave, emitted from smart agricultural sensors, E intensity of 370 V/m. However, we did not separated plants depending on their position in the pot, but chose them at random. Thus we might not have been able to detect an EMF plant response, due to difference in the absorbed energy between the plants at the edge and in the middle of the pot, so we sought such difference in this study.

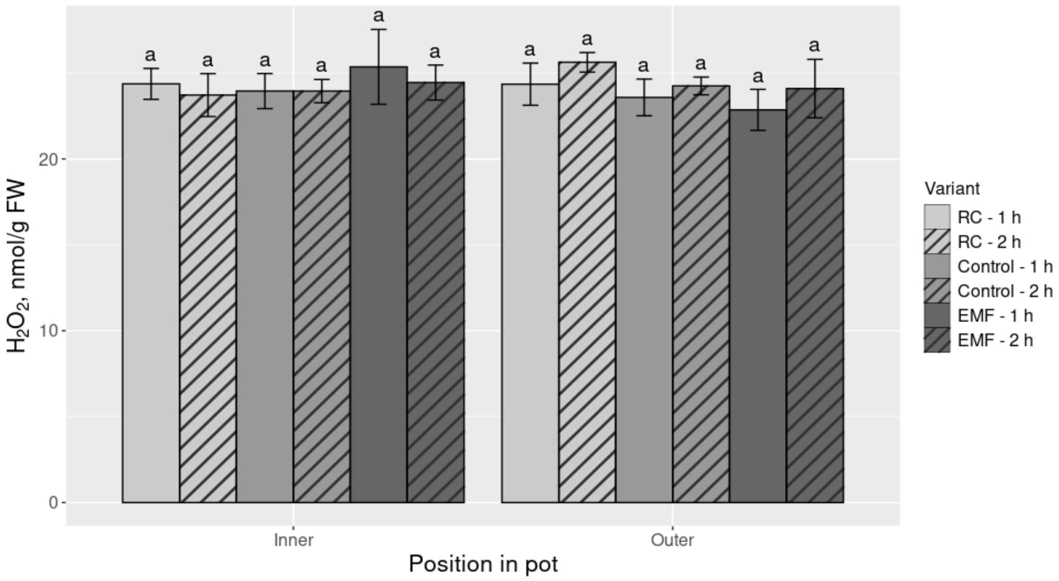

Figure 1. H_2O_2 content in second leaf of *Z. mays* plants which stayed in the growth chamber as referent control (*RC*), remained unexposed (*Control*) or were irradiated with 900 MHz electromagnetic field (*EMF*), from two positions of the growing pots: in the center, away from the antenna (*Inner*), and in the periphery, close to the antenna (*Outer*), one (*1 h*) and two hours (*2 h*) after the end of the treatment.

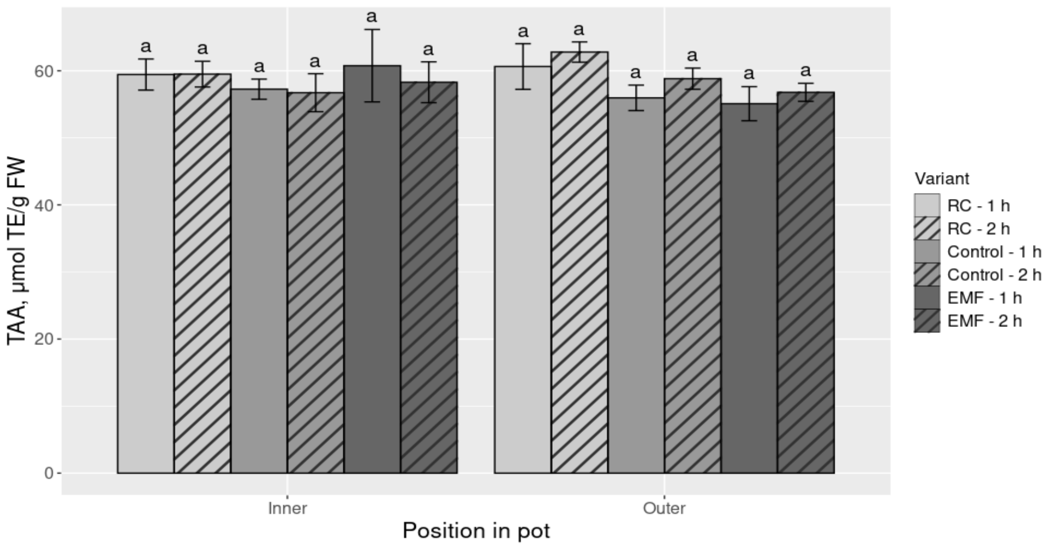

Figure 2. Total antioxidant activity (TAA) in second leaf of *Z. mays* plants which stayed in the growth chamber as referent control (*RC*), remained unexposed (*Control*) or were irradiated with 900 MHz electromagnetic field (*EMF*), from two positions of the growing pots: in the center, away from the antenna (*Inner*), and in the periphery, close to the antenna (*Outer*), one (*1 h*) and two hours (*2 h*) after the end of treatment.

The lack of EMF effect on redox status of maize leaves seems unexpected given many reports of oxidative stress induction in plants by EMF (Abbey *et al*., 2017, Kaur *et al*., 2021, Upadhyaya *et al*., 2022, Handa *et al*., 2024), even during exposure shorter than 2 hours. Moreover, it is much more peculiar considering the high intensity and vertical polarization, both assuring high energy absorption by the plants. However, it should be noted that not all of the leaves were oriented vertically to align with the E vector.

The main parameters determining the interaction between EMF and the matter is the frequency of the former and the chemical structure of the latter. Based on our observations, approximately 90% of *Z. mays* leaves consist of water (data not shown). Thus, water molecules are likely the main receptors of the EMF energy. At frequency of 900 MHz water has high absorption due to its high dielectric permittivity, but low dielectric loss, resulting in high polarization (reorientation to extrinsic E) ability and low heat dissipation of EMF energy (Chaplin, 2024). On the other hand, polarization of water molecules could affect biological macromolecules through the hydrogen bond network (Kaatze *et al*., 2002). Moreover, biomolecules themselves may have high EMF absorption at microwave frequencies (900 MHz being at the limit between RF and microwaves) but it is not considered significant due to, at least partly, the strongly dampening aqueous environment (Adair, 2002). However, our study did not reveal any specific biological effect arising from the EMF-water interaction at 900 MHz and this is in agreement with previous experiments with plants and GSM modulated signals (Kouzmanova *et al*., 2010).

No time-dependent dynamics of oxidants and antioxidants could be attributed to the chosen periods. An hour between the end of irradiation and sample preparation might be too long for a subtle oxidative stress to persist, allowing relaxation to redox homeostasis.

The lack of difference between *Inner* and *Outer* plants could be explained by the small size of the plants, which does not ensure effective screening. Under real conditions, larger plants with well-developed leaves would absorb EMF more efficiently.

CONCLUSIONS

Our results show that there was no statistically significant difference in the H_2O_2 content and in the TAA between the EMF exposed and control maize variants, as well as between the plants placed near to the antenna and those situated farther from it shaded by the first. Under the investigated exposure conditions 900 MHz EMF did not induce alterations in the redox status in young maize.

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