

MICROWAVES IRRADIATION EXPERIMENTS ON BIOLOGICAL SAMPLES

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SUMMARY. The goal of the present study was to investigate the effects of low power microwave irradiation, at 2.45 GHz, on plant samples. We choose the microwave power level used in wireless LAN communications between a wireless LAN Router and a local PC laptop. With this power level plants samples have been irradiated in specific experimental conditions. The irradiated plants were compared with non-treated plants. Reference and irradiated plants were phenotypically similar, but the growth was strongly correlated with microwave irradiation. The protein metabolism was activated under microwave irradiation, demonstrated by higher values of total soluble protein content in irradiated plants.

Keywords: microwave power density; pigments; protein content; izoenzymes.

Introduction

This experiment is part of a research program, which intends to decipher if low power microwave affect biological samples, more precise the growth and development of plants at a power level where the thermal effect of the microwaves is insignificant.

The effects of microwave irradiation on plants have scarcely been studied. However, some aspects of microwave irradiation have been investigated. Among the most interesting for practical applications the following studies can be mentioned: extraction of essential oils using microwaves (Saoud *et al.*, 2005), increased seed germination (Aladjadjiyan, 2002), elimination of microorganisms (Bhaskara *et al.*, 1998), increased oil production from rape seeds under microwave irradiation (Valentová *et al.*, 2000; Novotná *et al.*, 1999), stimulation of antioxidant activity in bean (*Vicia faba*)

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(Randhir and Shetty, 2004) or protection of cells against UV radiation (Chen, 2006). The use of controlled influence of physical factors on biological behavior during development of different cultures is a modern trend in combining plant technologies with the ecological requirements (Aladjadjiyan, 2007). Regarding the effects of microwave irradiation, gene expression in plants was affected (Vian *et al.*, 2006) or cytogenetic changes occurred (Pavel *et al.*, 1998).

In this study, the effects of microwave irradiation on germination of bean (*Phaseolus vulgaris* L.) and corn (*Zea mays* L.) seeds, on growth and development of plants have been investigated. The studied parameters were: a) seed germination, b) growth of shoots and roots, c) total soluble protein content, d) chlorophyll content and e) izoenzyme activities (peroxidase and superoxid-dismutase).

Materials and methods

Microwave irradiation. Experimental setup

The experiments were carried out in two identical anechoic chambers (I-Irradiated chamber, R- Reference 1 chamber) both with controlled environment (Fig. 1). Temperature and humidity sensors (SHT-17) (1) from I and R chambers were connected through a microcontroller system (2) to a personal computer (3) (Fig. 1).

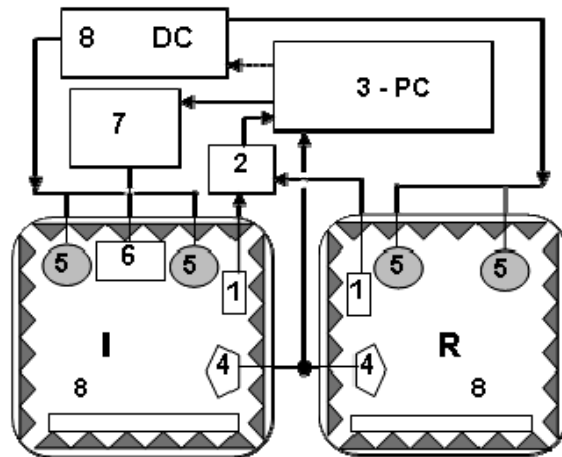


Figure 1. Experimental setup configuration. I and R are identical anechoic chambers, I-chamber for microwaves irradiations, R-chamber as reference without microwaves.

- (1) humidity and temperature sensors, (2) microcontroller, (3) personal computer,
- (4) WEB camera, (5) illuminating system, (6) microwave antenna,
- (7) microwave generator, (8) DC source, (9) ceramic pot.

A high sensitivity camera (SPC 900NC) (4) and multi-LED illuminating system (5) was also used in the experiment. The DC source (8) of the illuminating system was controlling the multi-LED illumination cycle. At the top of the I-st chamber one microwaves antenna (6) connected to a microwave generator (7) was installed. The inner volume of the experimental chambers was 24 cm^3 . The plants were placed in a ceramic pot (8) with 18 cm diameter and 3 cm height at the bottom of the chambers.

The microwave generator was a commercial dual band Wireless Router 802.11a+g (TEW-511BRP). The frequencies used ranged between 2.40-2.48 GHz (g-band) at a maximum output power of +17dBm. The connection from microwave generator to antenna was made with a microwave coaxial cable with 1.2dB attenuation. The microwave modulation signal, was the specific protocol of the Wireless Local Area Network (WLAN) connection known as Wireless Fidelity (Wi-Fi), in the “searching network users” mode (IEEE 802.11 Standard, 1997). This mode is characterized by intermittent emission ($\sim 1.5\text{ms}$ active, 100ms pause) of a specific modulated data on microwaves carrier and a specific sweep of the frequency in the chosen band. The operating mode and frequency channel are set using the router software via LAN connection, from the PC internet explorer interface. In our experiment the router was set on Channel 9 at 2.452GHz frequency.

Microwaves measurements

First the microwave power at the pot level was characterized and the measurement configuration is presented in Figure 2.

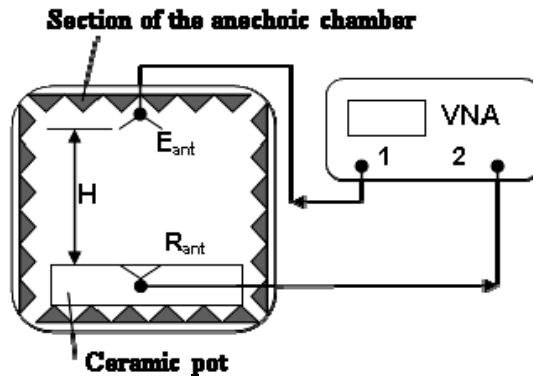


Figure 2. Microwaves power measurement configuration;

VNA is an Vector Network Analyzer, Agilent N5230A with two port “1” and “2”, E_{ant} is the emission antenna, R_{ant} is the reception antenna, H is the height of the chamber.

More precisely, the specific attenuation (A) of the anechoic chamber was measured. For this measurement two identical antennas E_{ant} and R_{ant} (with gain G) connected to one Vector Network Analyzer (VNA) were used. In fact this is an emission-reception link characterized by the equation:

$$P_t = P_r + A + 2G \quad (1)$$

Where: P_t is the transmitted power in (dBm) at the output “1” of the VNA, P_r is the received power in (dBm) at the input “2” of the VNA, A is the attenuation in (dB) of the anechoic chamber at the distance H from E_{ant} antenna and G is the gain of the antennas in (dBi).

Considering: $S_{12} = P_t - P_r$, where S_{12} is the transmission parameter measured by the VNA in (dB), the attenuation at the ceramic pot level is:

$$A \text{ (dB)} = S_{12} - 2G \quad (2)$$

In the Table 1 are presented the values of the principal parameters measured, for a set of two identical antennas. In these measurements the input power generated by the VNA was $P_t = 0$ dBm and $H = 175$ mm. Considering the antenna maximum dimensions (D), the anechoic chamber link respect the far field condition at the ceramic pot level (Foegelle, 2002):

$$H > R = 2D^2/\lambda$$

Where: D is the maximum antenna dimension, λ is the wavelength at the working frequency ($\lambda=122.3$ mm) and R is the minimum distance from emission antenna E_{ant} where we can consider homogeneous microwaves field.

The optimum height of the growing plants, to be in homogeneous microwaves field, is $H_{plant} = H - R$. In our experiment the maximum value for H_{plant} is 15 cm (Table 1).

Table 1.

Principal parameters on microwaves power characterization of the anechoic chamber.

G (dBi)	D (mm)	S_{12} (dB)	A (dB)	A_{cable} (dB)	R (mm)	H_{plant} (mm)	P_t (mW)	P_{pot} (μ W)
+2.20	80	-25.64	-29.64	-1.2	105	70	50	69
-3.68	29	-37.03	-29.67	-1.2	14	151	50	18

G - antenna gain, D – antenna maximum dimension, S_{12} – transmission parameter, A –specific attenuation of the anechoic chamber, A_{cable} – attenuation of the cable between microwave generator and emission antenna, R – distance from emission antenna where microwaves are homogeny distributed, H_{plant} – optimum height of plant to grown in homogeny microwaves, P_t – output generator power, P_{pot} – estimated microwave power at the pot level.

It is necessary to measure the change in attenuation (A) over this distance and a decrease in attenuation with less of $\Delta A_H = 0.2$ dB was found. Also, in the circular area of the ceramic pot, the measured variation in attenuation’s was less than $\Delta A_{pot} = 0.1$ dB. These values prove a good homogeneity of the microwave field in the considered volume.

To calculate the microwave power at the pot level is necessary to know the input power of the microwave generator (Fig. 1) used in experiment P_t (dBm), the gain G (dBi) of the antenna and the attenuation A (dB) at the distance H :

$$P_{\text{pot}} = (P_t - |A_{\text{cable}}| + G) - |A| = \text{EIRP} - |A| \quad (4)$$

Where EIRP is the effective radiated power compared to an isotropic radiator. In Table 1 are presented also the values of input power P_t and the power at ceramic pot P_{pot} for two antennas. If we consider all the measured variations of the chamber attenuation (ΔA_H and ΔA_{pot}) the maximum estimated microwave power at the pot level is $P_{\text{pot}} = (70 \pm 3)\mu\text{W}$. At this power, considering all microwaves transformed in heat, the temperature rate raising is less than $10^{-6} \text{ }^\circ\text{C/s}$ for the initial seeds-water volume, approximated as 40 ml of water. The measured power density at the ceramic pot level was $P_d \approx 0.005\text{mW/cm}^2$, which is 200 times lower than the ICNIRP recommendation (1mW/cm^2) for the environmental microwave safety power level (ICNIRP, 1998). During the experiments the measured difference in temperature of the Irradiated and Reference 1 chamber was less than $0.5 \text{ }^\circ\text{C}$, and the difference in relative humidity was less than 4%.

Plant material

The effects of microwaves were studied on bean (*Phaseolus vulgaris* L., cv. Ardeleana) and corn (*Zea mays* L., cv. Favorit) plants obtained from seeds. Experimental variants were: a) plants grown in a growth chamber at 24°C , under a 16 h light photoperiod with $39.06 \mu\text{Em}^{-2}\text{s}^{-1}$ photosynthetically active radiation (PAR) (Reference 0) (R0), b) plants grown in the anechoic chamber with controlled environment without microwaves irradiation (Reference 1) (R1) and c) plants grown in the anechoic chamber with microwaves irradiation (Irradiated) (I). The tested parameters were analyzed on plant material from the three experimental variants.

Seed germination and growth measurement

Seeds were sowed in laboratory vessels (18 cm in diameter and 3 cm in height) on humidified filter paper for germination (50 seeds / vessel). Tap water was added periodically to maintain filter paper humidity. Growth of plants was determined by measurement of hypocotyls, epicotyls and root length at the end of the irradiation period. The irradiation duration was 14 days for bean and 25 days for corn.

Determination of total soluble protein content

Plant material representing leaves (100 mg) was grounded with 1.5 ml phosphate buffer at $\text{pH} = 6.1$ on ice. The extract was centrifuged 15 min at 10000 rpm at 4°C and the supernatant was stored at 4°C until utilization. Total soluble protein content was determined spectrophotometrically at 595 nm wavelength (Bradford, 1976). For the standard curve bovine serum albumine (BSA) (Sigma) was used. Total soluble protein content was determined on fresh weight (FW) basis.

Determination of assimilatory pigment content

The absorbance properties of pigments facilitate the quantitative analysis of them. Total chlorophyll (chlorophyll *a*, chlorophyll *b* and carotenoids) content was determined spectrophotometrically at wavelengths 663 nm, 645 nm and 470 nm and calculated according to the Wellburn (1994) formula. The pigments were extracted in dimethylformamide (DMF) (Moran and Porath, 1980). For extraction leaves (about 50 mg) were incubated in 2.5 ml of DMF at 4°C for 48 h in dark conditions followed by centrifugation of the extract at 5000 rpm for 5 min.

Identification of isoenzymes

Young leaves were used for isoenzymes separation. Fresh leaves (100 mg) were mortared on ice with extraction buffer (w/v) containing 0.1 M Tris-HCl, pH 7.5, 1 mM EDTA, 10 mM MgCl₂, 10 mM KCl, 14 mM 2-mercaptoethanol, (2-mercaptoethanol was not added in buffer solution when peroxidases were analysed), 10-50 mg/ml polyvinyl-pirolidone-PVP-40) (Brinegar and Goundan, 1993). Samples have been centrifuged at 10000 rpm, 10 min at 4°C. The pellet was discarded and the supernatant was used for electrophoresis. Isoenzymes separation was accomplished by continuous PAGE without SDS by isoelectric focusing (IEF). Gel concentration was 5%. For gel preparation a stock solution of acrylamide/bisacrylamide mixed with ampholine A, pH=3.5-5.0/ampholine B pH=3.5-10.0 ratio 1:1, H₂O, ammonium persulphate 10% and Temed. Two buffers were used in cuvettes: 20 mM NaOH/10 mM H₃PO₄. Running was performed at 120 V for 1 h with a Consort device.

Histochemical identification of isoenzymes was performed according to several protocols described by (Pasteur *et al.*, 1987; Murphy *et al.*, 1990; Acquah, 1992). Some of them were modified by us. Peroxidases were identified using 0.05 M Na acetat, pH 5.0 in which we added in order 10 mg CaCl₂, 250 µl H₂O₂ 3%, 50 mg 3-amino-9-ethyl-carbazol, dissolved previously in 5 ml dimethylformamide. Peroxidases appear as red bands after 15-30 min. SOD were identified using 0.2 M Tris-HCl, pH 8.0 buffer in which we added in order 10 mg MgCl₂, 20 mg NAD, 10 mg PMS (phenazin-methosulphate), 10 mg MTT (3-(4.5-dimethylthiazolil-2)-5-dipheniltetrazolium bromide). SOD appears as white bands on blue gel.

Statistical analysis of results

All experiments were carried out with three independent repetitions and the results were expressed as the mean values ± standard deviation (SD). Data were analyzed by two-way analysis of variance (ANOVA) using the Tukey test for data comparison.

Results and discussion

Germination of seeds and growth of plants under microwave irradiation

The experiment was started with seeds and continued until the plants achieved approximately 15 cm in height (Fig. 3). In each chamber video cameras were placed for monitoring of growth and miniature sensors for temperature and humidity measurement. The temperature difference was less than 0.5°C between the reference R1 and the irradiated chambers and the humidity difference was less than 3% RH over the entire growing period. During the growth period the temperature variation was between 20°C to 24°C , the artificial illumination was continuous and the relative humidity was kept between 68 and 88% RH in both chambers. The microwave power at the plants-pot level was maintained at a value of less than -10dBm . The modulation was the WLAN standard protocol.

Germination percentages of seeds in the three mentioned experimental variants were significantly different for the same species (Table 2). Microwave irradiation influenced significantly only the germination of bean seeds in comparison with seed germination under R1 conditions. It is possible that the culture conditions could affect the germination rate. Regarding corn, the germination of irradiated seeds was different in comparison with the other two tested variants.

Table 2.

Germination percentages of bean (*Phaseolus vulgaris*) and corn (*Zea mays*) seeds

Plant material	Seed germination (% \pm SD)*		
	Reference 0	Reference 1	Irradiated seeds
bean	$99.0 \pm 1.41^{\text{a}}$	$95.9 \pm 2.79^{\text{b}}$	$98.9 \pm 1.44^{\text{a}}$
corn	$95.0 \pm 1.41^{\text{b}}$	$94.9 \pm 1.50^{\text{b}}$	$96.9 \pm 1.47^{\text{a}}$

* Data represent means \pm SD. Values followed by the same letter within a row are not significantly different ($P < 0.05$).

Plant growth and development involves complex morphological, physiological, biochemical and molecular processes. Plants developed under the experimental conditions in the anechoic chambers (with and without irradiation) were phenotypically similar to the plants grown in the growth chamber. It was noted a stimulating effect of the microwaves on plant growing for both species (Fig. 3). Generally the length of bean and corn plants under irradiation conditions was higher than for reference plants. The highest values for growth after the end of the irradiation period (14 days for bean and 25 days for corn) were noted for the epicotyl with 12.5 cm for bean and 8.2 cm for corn (Fig. 4A, B). The stimulation effect of microwaves was observed also for hypocotyles and roots. In this case the mean length of irradiated hypocotyles was 5.7 cm for bean and 2.2 cm for corn. The length of irradiated roots was 12.1 cm for bean and 7.9 cm for corn (Fig. 4A, B).

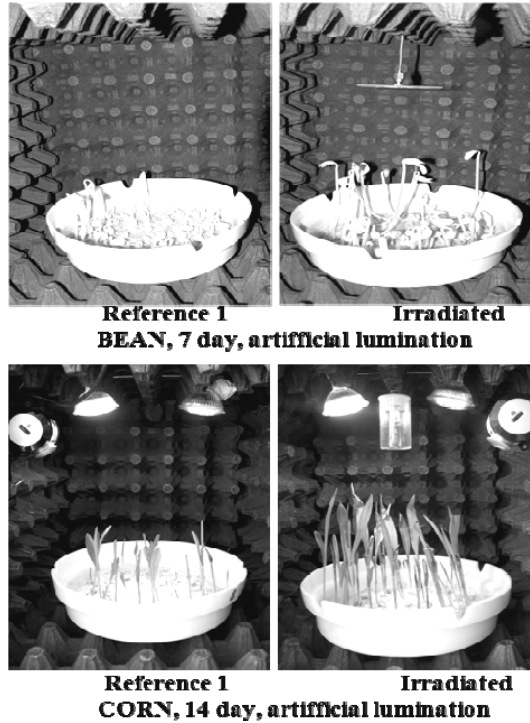


Figure 3. Effects of microwave irradiation on growth of bean (*Phaseolus vulgaris*) and corn (*Zea mays*) plants. A) plants grown in the reference anechoic chamber; B) plants grown under irradiation.

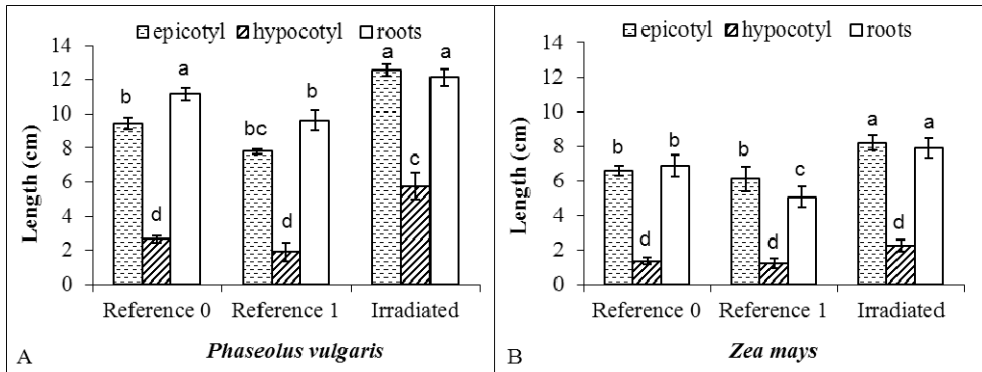


Figure 4. Effects of irradiation on growth of bean (*Phaseolus vulgaris*) (A) and corn (*Zea mays*) (B) plants. Measurement of hypocotyls, epicotyls and root length was made at the end of the irradiation period (14 days for bean and 25 days for corn). Vertical bars represent standard deviations. Different letters are significantly different ($P < 0.05$).

The stimulation effect of cell division was reported also for *Catharanthus roseus* protoplasts following growth in magnetic field (Haneda *et al.*, 2005).

Effects of microwave irradiation on totale soluble protein content

The comparative study of totale soluble protein content in the leaves of bean and corn plants showed differences between species and the experimental variants (Fig. 5A, B). It was noted a high value of protein content in the leaves of irradiated plants (Fig. 5A, B). At the end of the irradiation period (14 days for bean and 25 days for corn) the protein content was 0.27 $\mu\text{g/g}$ FW for bean and 0.25 $\mu\text{g/g}$ FW for corn. The values representing the content of total soluble protein content for reference 0 and reference 1 were almost similar. After prolonged irradiation duration the protein content was lower for both species. Changes in protein expression, accumulation and synthesis in tomato plants have been observed in stress conditions (Chen and Tabaeizadeh, 1992). Numerous physiological and biochemical changes occur in response to stress factors in various plant species. The physiological mechanisms involved in cellular response to stress factors generated have been investigated (Turner, 1997; Neuman, 1997).

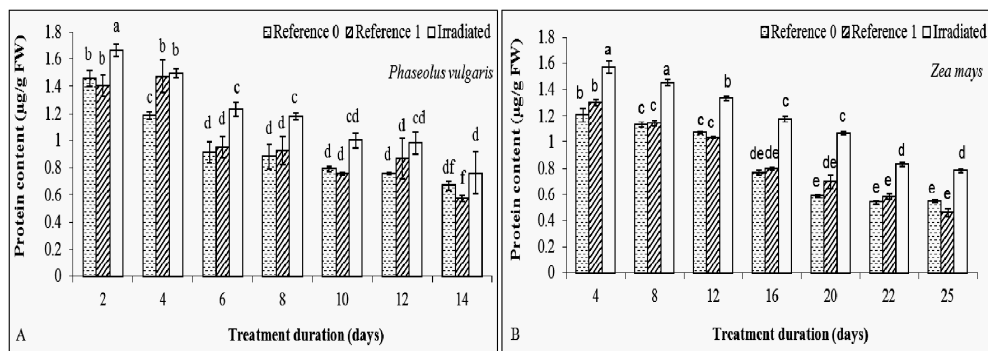


Figure 5. Effects of microwave irradiation on total soluble protein content on fresh weight basis in the leaves of reference and irradiated bean (*Phaseolus vulgaris*) (A) and corn (*Zea mays*) (B) plants. Vertical bars represent standard deviations. Different letters are significantly different ($P < 0.05$).

In accordance with the obtained data we can conclude that the protein metabolism was stimulated and activated under microwave treatment.

Effects of microwave irradiation on assimilatory pigment content

Following 2 weeks of growth of bean plants under microwave irradiation conditions the content in chlorophyll *a+b* was 0.54 mg/g FW whereas after the same period the content in chlorophyll *a+b* in reference 0 plants was 0.42 mg/g FW and in reference 1 plants was 0.57 mg/g FW (Fig. 6A). The content in carotenoids obtained

for the same period showed differences for the experimental variants with 0.38 mg/g FW for irradiated plants, 0.32 mg/g FW for reference 0 plants and 0.29 mg/g FW for reference 1 plants (Fig. 6B).

In leaves of corn plants following 25 days of irradiation the content in chlorophyll *a+b* was 0.29 mg/g FW. In the other experimental variants the content in chlorophyll *a+b* was 0.30 mg/g FW for reference 0 and 0.29 mg/g FW for reference 1 (Fig. 6C). The values representing the content in carotenoids were 0.26 mg/g FW for irradiated plants, 0.23 mg/g FW for reference 0 and 0.24 mg/g FW for reference 1 plants (Fig. 6D). For corn the differences in chlorophyll *a+b* and carotenoids between categories were not significantly different. The results of the experiment showed that chlorophyll *a+b* content in bean is stimulated by microwave irradiation exposure. Higher values of carotenoids could be due to the stress protective function of carotenoids which has been well-established (Eskling *et al.*, 1997). Anthocyanin accumulation is known as a characteristic in stress conditions (Eryilmaz, 2006). It is to note that irradiation did not affect negatively the synthesis of chlorophylls in none of the tested species. These results suggests that microwave radiation enhanced plant metabolism. An increased content in chlorophyll *a*, *b* and carotenoids was noted also under growth of potato (*Solanum tuberosum* L.) in vitro cultures in null magnetic field (Rakosy *et al.*, 2005). The chlorophylls and carotenoidic pigments content are biochemical indicators for the physiological processes in plants. Analyses of chlorophylls and carotenoids in this case have not proved differences between the microwaves irradiated plants and the references in the anechoic chamber.

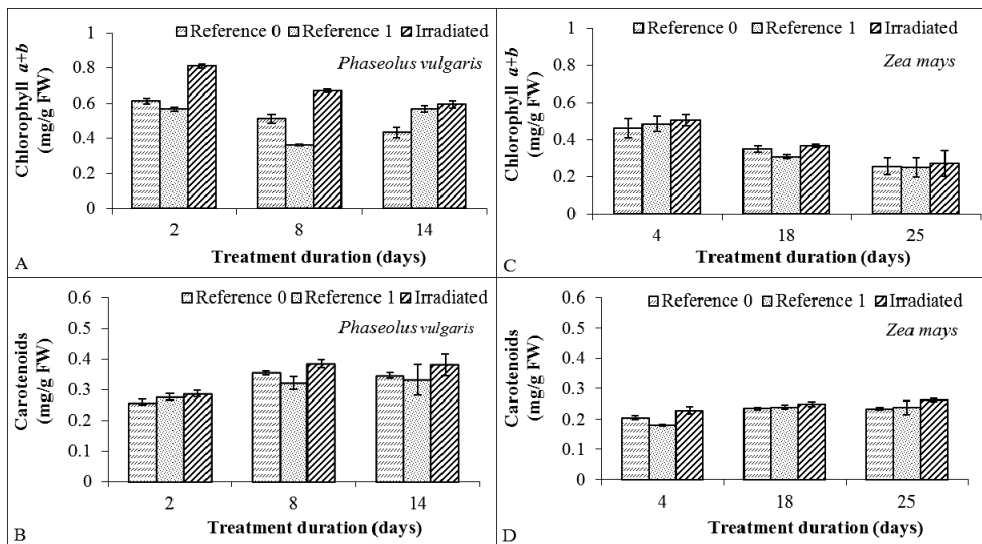


Figure 6. Effects of microwave irradiation and dynamics of pigment contents in the leaves of reference and irradiated bean (*Phaseolus vulgaris*) plants (A, B) and reference and irradiated corn (*Zea mays*) plants (C, D). Vertical bars represent standard deviations.

Study of isoenzymes

The isoenzymatic profile of peroxidases expressed in leaves of corn plants exposed to microwave irradiation is shown in Fig. 7. The pH gradient created in the gel with ampholines is ranged between 9 (in the upper part of the gel) and 3 (at the lower part of the gel). As it could be seen most of the peroxidases are located in the alkaline region of electrophoresis gel. The izoperoxidase pattern is the same in reference plants and plants exposed to microwaves. Five alkaline izoperoxidasas have been revealed in all plants having, isoelectric points between 9 and 6. In the neutral region of pH gradient in the gel, only one izoperoxidase have been expressed, this is also present in all plants, reference and exposed to microwaves as well. In sample 1, an other neutral izoperoxidase was observed. In the acid region of the pH gradient in the gel only one izoperoxidase have been observed. This izoperoxidase was expressed only in sample 1 and 13, and is not correlated with microwave exposure. It is well known that the acid peroxidases are located prevalent in the cell wall being involved in the polymerization of the monomers of lignine. Alkaline peroxidases are usually involved in plant respons to different stress factors (Gaspar *et al.*, 1996).

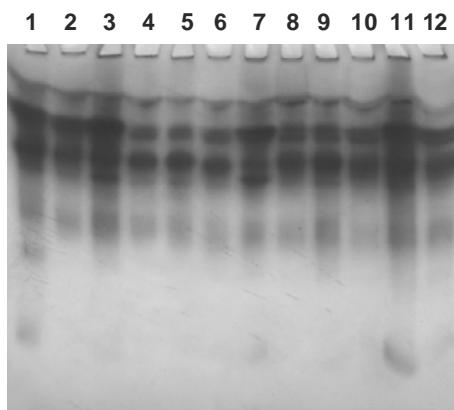


Figure 7. Isoenzymatic profile with IEF of peroxidase expressed in leaves of corn plants exposed to microwaves.

(1) reference 0 – after 2 days; (2) reference 1 – after 12 days; (3) irradiated – after 12 days; (4) reference 1 – after 16 days; (5) irradiated – after 16 days; (6) reference 1 – after 20 days; (7) irradiated – after 20 days; (8) reference 1 – after 22 days; (9) irradiated – after 22 days; (10) reference 1 – after 25 days; (11) irradiated – after 25 days; (12) reference 0 – after 25 days.

Peroxidasas in higher plants could be clasified in two major groups, according to their functions and specificity of substrate. The guaiacol peroxidases (GPX) have low specificity of substrate and it seems to have different peroxidative functions in the cell. The other peroxidases as glutation peroxidase (Beeor-Tzahar *et al.*, 1995) and ascorbat peroxidase (APX) (Asada, 1992) are crucial for neutralization of H₂O₂, organic hydroperoxides and lipid peroxides. Up to now, GPX have been found in

the vacuoles, cell wall, cytosol, extracellular space and corn mitochondria (Asada, 1992; Prasad *et al.*, 1995), whereas APX are present mainly in chloroplasts and partially in cytosol and glyoxisomes (Asada, 1992; Asada *et al.*, 1993; Mittler and Zillinskas, 1993; Bunkelmann and Trelease, 1996). Extracellular peroxidases play an important role in plant response to stress factors. Thus, the peroxidases are involved in the neutralization of free radicals produced by oxidation of AIA, monoamines, salicylic acid and kitoolygozaharides (Kawano *et al.*, 2000). Peroxidases modulates the redox equilibrium of the cell being involved in plant development (Broin *et al.*, 2002) and the signal transduction mediated by calcium that is necessary for induction of plant response against stress factors (Kawano, 2003). Moreover, it was already demonstrated that APX1, one of the peroxidases from *Arabidopsis* is the central component in the complex of the enzymes involved in the neutralization of free radicals (Davletova *et al.*, 2005). It has been demonstrated that APX F, a peroxidase from mitochondria is essential for homeostasis and root growth in *Arabidopsis* under different stress conditions (Finkemeier *et al.*, 2005). As it is shown in Fig. 7, there is no isoperoxidase expressed only plants exposed to microwaves. It could be concluded that the irradiation of corn plants with microwaves power density of $P_d = 0.005\text{mW/cm}^2$, is not associated with any changes in the pattern of peroxidases, so in these plants could be not detected isoperoxidases that usually are induced in stress conditions. Unlike peroxidases that are extremely inducible with different stress factors and plants development there are other enzymes involved in neutralization of free radicals as superoxid dismutases and esterases (Dobrota *et al.*, 2003, 2004). Isoenzymatic profile of SOD isoenzymes is shown in Fig. 8. In the alkaline region of pH gradient in the gel, two isoenzymes have been observed, their expression being similar in reference plants and plants exposed to microwaves.

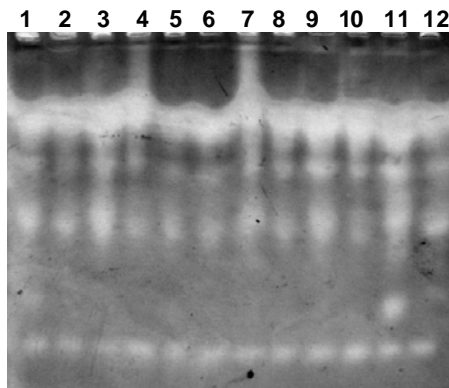


Figure 8. Isoenzymatic profile with IEF of superoxide dismutase expressed in leaves of corn plants exposed to microwaves.

(1) reference 0 – after 2 days; (2) reference 1 – after 12 days; (3) irradiated – after 12 days; (4) reference 1 – after 16 days; (5) irradiated – after 16 days; (6) reference 1 – after 20 days; (7) irradiated – after 20 days; (8) reference 1 – after 22 days; (9) irradiated – after 22 days; (10) reference 1 – after 25 days; (11) irradiated – after 25 days; (12) reference 0 – after 25 days.

In neutral region of pH gradient, only one isoenzyme was expressed in all plants. In acide region of pH gradient, only one isoenzyme was expressed accidentally, in sample 1 and 13. An other isoenzyme having an isoelectric point arround 3, have been expressed in all plants. Similar to izoperoxidase pattern, the SOD pattern does not reveal any isoenzyme associated with plants exposure to microwaves. Because the enzyme SOD is involved in controlling the superoxide radical, its activity suggests that microwaves power density of $P_d = 0.005\text{mW}/\text{cm}^2$ does not induce stress effects on these plants. Reactive oxygen species are generated as by-products of metabolism mainly in chloroplast (Assada, 2000, 2006) but they are also produced in peroxisomes and the cell wall (Dat *et al.*, 2000). Oxidative overproduction of ROS may be induced by a wide spectrum of abiotic and biotic stress factors, but in our experiment could be not detected such changes in SOD activity.

Conclusions

Growth was strongly correlated with irradiation of plants. A stimulating effect of cell division under microwave irradiation was noted. Plants grown in reference and irradiated conditions were phenotypically similar. The protein metabolism was activated under microwave irradiation, demonstrated by higher values of total soluble protein content in irradiated plants. Chlorophyll concentration was not strongly affected by microwave irradiation in comparison with chlorophyll content in reference leaves.

The irradiation of corn plants with microwaves is not associated with any changes in the pattern of peroxidases and SOD, wich suggest that this intensity of microwaves does not induce stress effects on these plants. The results presented revealed that microwaves power density of $0.005\text{mW}/\text{cm}^2$, did not activate other enzymatic systems besides the usual ones in normal physiological conditions for maintenance of cell homeostazy.

Microwave irradiation as a physical method for increasing the vegetable production could be used for seeds or plant treatment with the goal of accelerating plant growth and development.

Further experiments involving exposure of other plant species and different periods of time and various wavelengths would be necessary to establish other effects of microwaves on plant development.

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