EFFECT OF MICROWAVE IRRADIATION ON SEEDS OF LENTILS (*LENS CULINARIS*, MED.)

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Abstract. This paper presents the investigation of the influence of microwave irradiation treatment on the development of lentil seeds (*Lens culinaris*, Med.). A magnetron OM75P(31) emitting radiation with frequency 2.45 GHz has been used as a source of microwaves for the experiment. The exposure time varied from 0 s, 30 s, 60 s, 90 s, and 120 s. The germination energy (*GE*) and germination (*G*) of seeds in %, as well as the length of stems (*SL*) and roots (*RL*) in mm at 7^{th} and 14^{th} day after sowing, and the total weight (*TW*) at 14^{th} day have been measured aiming to estimate the influence of microwave treatment. Best results have been obtained for variants with exposure time 30 s and output power 450 W – *SL* measured at 7^{th} day is 10% longer than the control one, *RL* – 7%, and *TW* at 14^{th} day is 16% higher. Longer exposure times have an inhibition effect on plant development as well as higher output power of microwave irradiation. Obtained results have been explained by the hypothesis that bigger energy absorbed by molecules at higher output power and longer exposure time could destroy cell functions and stimulation effect could not be achieved.

Key words: microwave irradiation, stimulation, lentils, germination, stem, root length, total weight.

INTRODUCTION

Recently, Banik *et al*. [6] reviewed the bioeffects of microwave, mostly on animal and human health. In their paper the most popular opinion has been outlined, that the effect of microwave is attributed mainly to the heating. Nevertheless, it has been mentioned that there are also non–thermal microwave effects in terms of energy required to produce molecular transformations.

It has been accepted, [7], that the thermal effect of microwave is related to the interaction with charged particles and polar molecules. Microwave fields are a form of electromagnetic energy and its interaction with charged particles and polar molecules leads to their agitation which is defined as heat. Biological material placed in such radiation absorbs an amount of energy which depends on the dielectric characteristics of the material. The thermal effect of electromagnetic

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fields from radiofrequency diapason on biological objects is evaluated by Specific Absorption Rate (SAR), defined as the power absorbed per mass of tissue and measured in W kg^{-1}. The use of SAR for assessment of microwave impact is reported in literature for different biological objects but not for seeds.

In most of the published investigations concerning agriculture the microwave treatment has been used for disinfection of seeds before sowing. Bhaskara Reddy *et al*. [11, 12] used successfully the treatment with electromagnetic radiation from the radio- (10–40 MHz) and microwave diapason (2.45 GHz) on seeds of mustard, wheat, soybean, peas and rice seeking to eliminate the microorganisms (*Fusarium graminearum*) before seed storage. Similar aims have been described in the PhD thesis of V. Rajagopal [10]. He has treated grain seeds with microwave radiation aiming disinfection, too. In his work a pilot–scale industrial microwave dryer operating at 2.45 GHz was used to determine the mortality of life stages of *Tribolium castaneum* (Herbst), *Sitophilus granarius* (L.) and *Cryptolestes ferrugineus* (Stephens) adults in wheat, barley, and rye. In the listed works there were no data about SAR evaluation.

Some authors have investigated the influence of microwave treatment on different properties of seeds. Yoshida *et al*. [13] treated soybean seeds with microwave radiation (2.45 GHz) for 6 to 12 min with the aim to improve the distribution of triglycerides in the seed coat. L. Oprică [8] has studied microwave treatment with power density under 1 mW/cm^3 on rapeseeds (*Brassica napus*) and concluded that the microwaves determined variations of catalase and peroxidase activities depending on the age of the plants, time of exposure and state of seeds (germinated and non germinated) exposed to microwave. In all above-mentioned studies the microwave treatment was oriented to produce effects not related to plant stimulation.

Ponomarev *et al*. [9] investigated the influence of low intensity microwave radiation on the germination of cereals (winter and spring wheat, spring barley, oats). Radiation with wavelength $\lambda = 1$ cm at exposition up to 40 min was used. An increasing of germination for all the treated seeds was observed, the optimum effect of stimulation being accounted at the exposition for 20 min.

The treatment with microwave radiation as a stimulation agent in agriculture is not enough investigated yet. Recent data about environmental pollution caused by large application of chemical agents used for fertilization and plant protection urged farmers to search some alternative methods. Physical methods of treatment offer good opportunities for substitution of chemical ones [2, 3]. They are convenient for organic agriculture. The stimulation effect of microwave treatment has been investigated by Aladjadjiyan and Svetleva previously on bean (*Phaseolus vulgaris*) [4] and on some ornamental perennial species *Caragana arborescens*

Lam*.*, *Robinia pseudoacacia* L*.*, *Gleditsia triacanthos* and *Laburnum anagyroides* Med. [1] and some encouraging results have been established.

The aim of present work is to enlarge previous experiments on stimulation effect of microwave treatment for longer exposure time and higher irradiation power by investigating its influence on the early stage development of lentil seeds (*Lens culinaris* Med.).

MATERIALS AND METHODS

The influence of microwave irradiation with wavelength 12 cm on seeds of lentil (*Lens culinaris,* Med) has been investigated. A magnetron OM75P(31) with frequency of radiation 2.45 GHz and maximum output power 900 W according to supplier's data has been used as microwave source. Maximum density of irradiation has been estimated at 45 kW/m^3. The estimation has been obtained by dividing the output power of the device (900 W) to the working volume having dimensions 0.19×0.33×0.32 m^3.

Lentils seeds have been preliminarily soaked in distilled water for 1 hour, presuming that the imbibed water plays an important role in the absorption of the energy of microwave radiation. (In an earlier investigation Aladjadjiyan and Svetleva [4] have found that preliminary soaking of seeds in distilled water increased the effect of stimulation by more than 25% due to the specific absorption of microwave radiation with wavelength of λ = 12 cm by the water molecules.)

Seeds for the experiment have been distributed in five variants and 5 replicates each containing 10 seeds. The variants differ by the time of exposure to the microwave radiation. Seeds have been exposed to the microwave radiation for 0 s (control), 30 s, 60 s, 90 s, 120 s. Two modifications of output powers of magnetron – 450 W and 730 W*,* corresponding to intensities – 22.5 kW/m^3 and 36.5 kW/m^3 respectively, have been applied.

The experiments have been performed in the period end of February – March 2009 under laboratory conditions. The natural light cycle was 9 h – light / 15 h – darkness and the daily temperature 21 ± 2 ºC, night temperature 15 ± 2 ºC.

Groups of 50 seeds were subjected to each microwave treatment, for chosen exposure times and analogous groups were used as control. The lentil seeds were cultured then in small plastic pots (Ø = 7.5 cm and *h* = 8.8 cm), 10 seeds in each pot, on wet cotton.

In order to estimate the influence of the microwave treatment on lentil seeds next criteria have been chosen:

- The germination energy (*E*) of seeds in%, determined on the 4th day after the start of the experiment – as a ratio of the number of germinated to the total number of seeds for the corresponding variant;
- germination (*G*) of seeds in%, determined on 7th day as a ratio of the number of germinated to the total number of seeds;

- length of stems (*SL*) and roots (*RL*) in mm has been determined on the 7th and 14th day;
- total weight (*TW*) in mg determined on the 14th day.

Data were statistically processed using the Fisher's method of dispersion analysis.

RESULTS AND DISCUSSION

The results of the experiments for lentil seeds have been presented in Table 1 for microwave irradiation with output powers 450 W (density of irradiation 22.5 kW/m^3) and 730 W (density of irradiation 36.5 kW/m^3), respectively. Results are presented as average value ± standard error. The significance of differences $GD_{P\%}$ is marked on the data in the table as a superscript.

Table 1

Growth parameters of lentils' seeds, exposed to microwave irradiation at 450 W and 730 W

Exposure time (s)	***GE* (%)**		***G* (%)**	
	450 W	730 W	450 W	730 W
control	82±4.8	78±3.7	92±4.9	90±2.5
30	90±4.5***	72±7.7 ^{ns}	96±2.5***	92±2.9*
60	76±14***	68±8.6*	86±8.5***	54±10.3 ^{ns}
90	14±7.4***	58±9.1***	14±10.4***	16±16***
120	6±2.5***	0	0	0

Superscript *** corresponds to $GD_{0.1\%}$; ** – $GD_{1\%}$; * – to $GD_{5\%}$, and ^{ns} – not significant.

Data in Table 1 show the influence of microwave treatment on the first stages of plant development is described by both characteristics – germination energy and germination. It can be noticed that for microwave treatment with output power 450 W the highest results for *GE* and *G* have been obtained for the exposure time 30 s. This exposure time has shown stimulation effect. All data were significantly different from control. For irradiated samples *GE* has risen with 9.8%, while *G* – with 4.3%.

The microwave treatment with output power 730 W shows that as well as in the case of treatment with 450 W, the values of *G* also demonstrate an effect of stimulation for the exposure time 30 s. The differences for *GE* at exposure 30 s and *G* at exposure 60 s from the control are not significant. An inhibition of *GE* can be accounted for longer exposure time (60 and 90 s) as well as for *G* at exposure 90 s.

The comparison of data for 450 W and 730 W allows concluding that the positive effect of treatment is generally stronger for the lower output power of microwave irradiation – 450 W. Shorter exposure time (30 s) demonstrates higher stimulation effect than longer ones. Exposure time 120 s causes total inhibition.

Figure 1 presents stem and root length, measured on the 7th day, for lentil plants treated with microwave with output power 450 W. Samples exposed to radiation for 30 s demonstrate the biggest stem and root length values while higher exposure times again lead to decreasing of plant size. For exposure 30 s *SL* is 10% longer than the control one, and *RL* – 7%. For the samples exposed 60 s *SL* is 9% shorter than the control one, but *RL* is 6.5% longer (statistical significance is between 1 and 5%). One can arrive at the conclusion that the stimulation effect of microwave treatment with exposure 30 s continues on the later stages of plant development. Some positive effect is detected also for the samples with exposure 60 s.

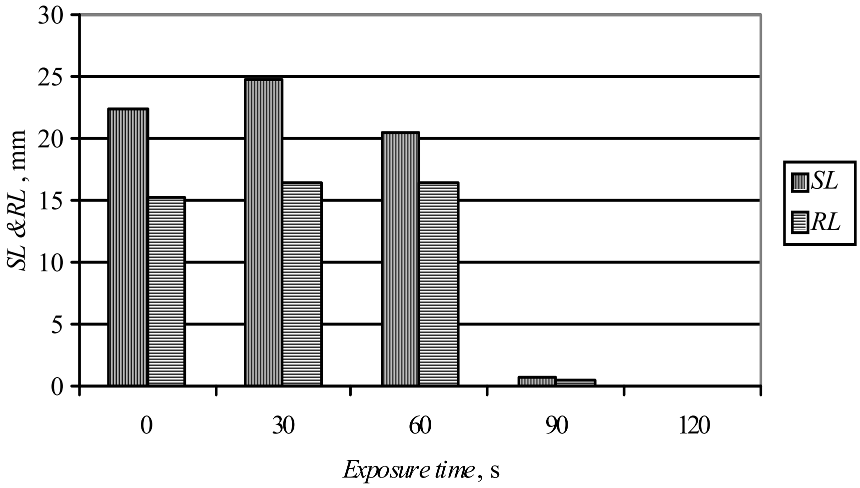

Fig. 1. Stem and root length of lentils seeds treated with microwave radiation with output power 450 W at 7th day of experiment.

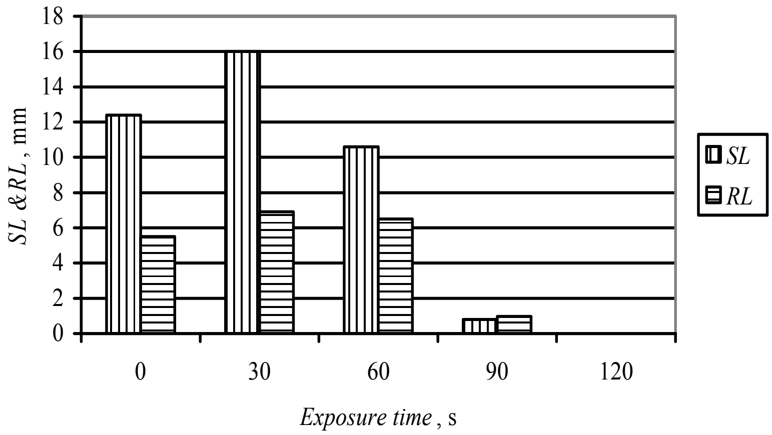

Fig. 2. Stem and root length of lentils seeds treated with microwave radiation with output power 730 W at 7th day.

Figure 2 presents stem and root length on 7th day *vs*. exposure time for microwave with output power 730 W. The biggest stem length is observed for exposure 30 s but the differences are not significant. A stimulation effect is observed for root length at exposure 30 and 60 s but the differences are not significant either. The longer exposure times show an inhibition. It can be noticed that at higher radiation intensity the positive effect of microwave stimulation is weaker.

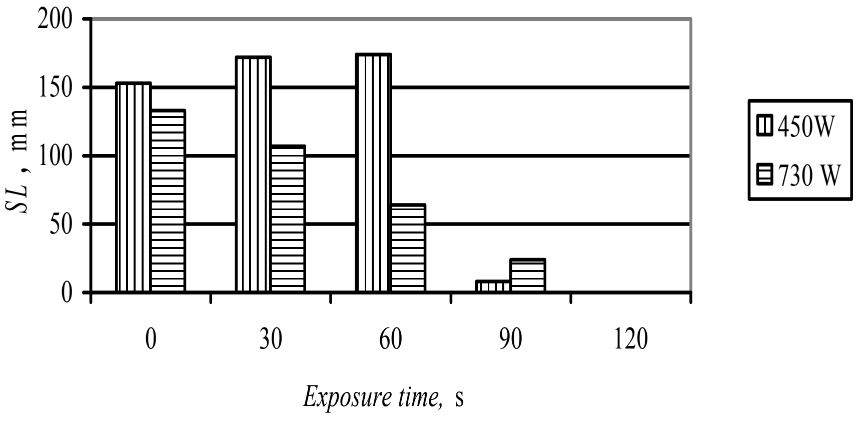

Fig. 3. The stem length of lentils seeds treated with microwave radiation with output powers 450 W and 730 W at 14th day.

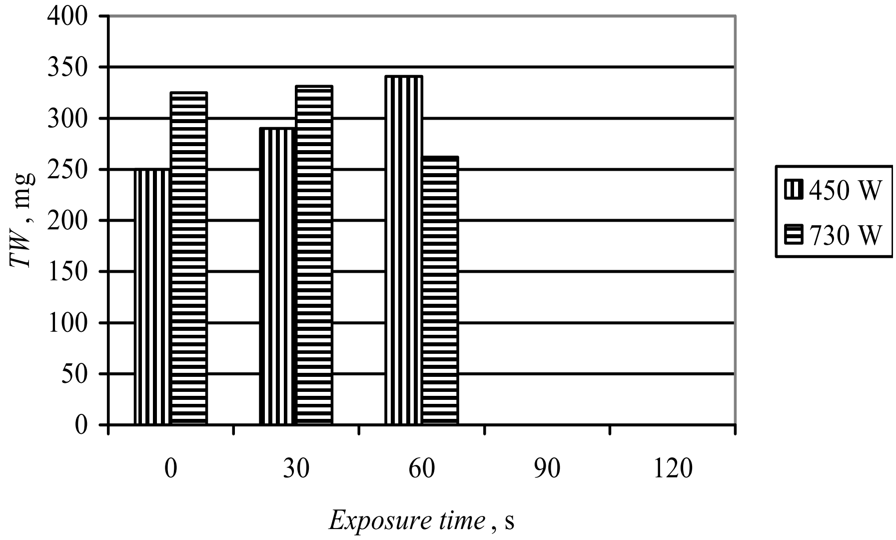

Fig. 4. The total weight of lentils seeds treated with microwave radiation with output powers 450 W and 730 W at 14th day.

Figures 3 and 4 illustrate the comparison of the influence of two applied microwave output powers – 450 and 730 W – for plant characteristics measured on the 14th day. It is clearly demonstrated that the treatment with lower output power, 450 W, gives better results. All data for the measurements on the 14th day were significantly different from control (statistical significance mainly between 0.1% and 1%).

It can be seen that the stem lengths (Fig. 3) have higher values for the plants treated with 450 W than with 730 W. The positive effect is accounted for the exposure times of 30 and 60 s. For the treatment with 450 W at exposure 30 s the value of *SL* is 12.5% longer than the control one and for exposure 60 s the *SL* is 13.7% longer. For the treatment with 730 W the values of *SL* are shorter than the control. All the differences are significant.

The total weight (Fig. 4) of plants *vs*. exposure time rises for the treatment with 450 W and for the one with 730 W there is a maximum at exposure 30 s.

Total weight for the samples treated with 430 W at 30 s is 16% higher, and for those at 60 s *TW* is 36.4% higher than the control. One can conclude that for 450 W the exposure at 60 s is more effective in later stages of development than the exposure at 30 s. A controversy with the data about *RL* could be noticed. Data in Table 1 and Table 2 show that at exposure 30 s *RL* is 3% longer, but at 60 s *RL* is 30% shorter than the control. This controversy could be due to the fact that the *RL* only of the main root is measured; but there are lateral roots that contribute to the weight and are not accounted for *RL*. This explanation refers also for the accounted rise of *TW* with 5% for the samples, treated with 730 W at exposure 30 s.

The results obtained in this investigation harmonize well with our previous investigations on bean seeds [4] and perennials [1].

In the case of bean seeds [4] the treatment was performed for exposure 10, 20 and 30 s. It has been found that the longer the treatment, the higher stimulation was achieved expressed in bigger fresh weight of roots and germs. In the present work we used longer exposure times, but the positive results were proved only for the exposure 30 s.

Experiments at exposure 30 s and different output microwave powers have been performed on seeds of the ornamental perennial species [1]. The investigation showed an increase of *G* and *GE* for *Gleditschia triacanthos* and *Robinia pseudoacacia*, proportional to the treatment power. For the seeds of *Caragana arborescens* and *Laburnum anagiroides* an increase of *G* and *GE* was reported for treatment with lower power. At higher power the seed germination was lower than the value of *G* at the lower power. This result correlates with the observation in present work, having found that the treatment with lower output power demonstrates better stimulation of seed development.

CONCLUSIONS

On the basis of the results obtained in the present investigation of the stimulation effect of microwave treatment on seed development, the following conclusions can be formulated:

1. Better results have been obtained for the treatment with lower output microwave power 450 W than 730 W.
2. Stimulation is stronger for the treatment at shorter exposure time – for 30 s than for 90 s and 120 s.
3. The positive effect of stimulation is better expressed for later stages of development – on the 14^{th} day.

These results can be explained in terms of absorbed energy. Higher output power of the radiation as well as the longer exposure time lead to absorption of bigger energy by the object.

As cited in the review of Banik *et al*. [6] the electromagnetic radiation from microwave diapason is absorbed at molecular level and manifests as changes in vibrational energy of molecules or heat. Higher energies cause heating [5].

In our investigation it is not definitely clear whether thermal effects of microwave are not involved. Further investigations with estimation of SAR are needed to understand if the impact of microwave treatment on seed development is due to thermal or athermal effects.

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