THE IMPACT OF MICROWAVE RADIATION AT DIFFERENT FREQUENCIES ON WEIGHT OF SEED POTATO GERMS AND CROP OF POTATO TUBERS

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Abstract. The purpose of this work was to examine the impact of microwave radiation at frequencies ranging within (2.45-54) GHz on selected potato plant life processes. Completed research allowed to find positive impact of microwave radiation at frequency 2.45 GHz on the weight of irradiated seed potato germs, and on the weight of Felka Bona variety potato tubers crop. This impact was not observed for microwave radiation at the following frequencies: 38 GHz, 46 GHz, and 54 GHz.

Key words: potato, germination, cropping, microwaves

Introduction

In order to acquire high quality raw material from plants and increase crops it is needed to improve seed materials. Pre-sowing processing of seed materials may be carried out using chemical agents and physical methods. Usually, chemical methods involve treating sowing material with proper substances, often toxic, which penetrate into the seed, thus interfering in its structure and modifying its chemical constitution. According to Pietruszewski [1993], physical methods do not cause any changes in germ chemical constitution but they modify physiological processes. Differences in effects resulting from application of the quoted methods indicate that compared to chemical methods, the physical ones may constitute an alternative for sowing material improvement, especially as regards ecological preparation of crops.

Deviatkov et al. [1981], Pichko et al. [1996 ab], and Mahendra et al. [1999] were carrying out studies concerning microwave radiation impact on organic structures, coming to a conclusion that biological effects primarily depend on frequency, duration and power of applied radiation. The issue of the impact of microwave radiation at different frequencies on sowing material, in the aspect of later plant growth, was the subject of experiments carried out in Poland and abroad [Górecki et al. 2004]. Olchowik et al. [1996, 1997] conducted a research concerning the impact of microwave radiation at frequencies ranging within (37.5÷54.04) GHz on seeds of the following plants: flax (*Linum usitatissimum* L.), buckwheat (*Fagopyrum esculentum* Mnch.) and cucumber (*Cucumis sativus* L.). They

observed positive impact of this physical factor on seed germination energy and crop structure. After irradiation of sunflower (*Helianthus L.*) seeds with microwaves at frequency 2.45 GHz, Kalinin et al. [2001, 2005] found their higher resistance to action of some pathogens. When examining the impact of pre-sowing irradiation of wheat seeds (*Triticum* L.) with microwaves at frequency 2.45 GHz (as a seed-heating factor), Warchlewski et al. [2007] did not find any influence of this factor on seeds microstructure, however they observed the impact on seed germination ability. Wójcik et al. [2004] conducted a research concerning the impact of microwave radiation at frequencies 38.46÷53.57 GHz on cropping and technical quality of sugar beet roots (*Beta vulgaris*), observing substantial radiation influence on roots crop, and content of sugar and molasses forms. Experiments covering the impact of microwave radiation at frequency 2.45 GHz on potato plants were initiated by Marks et al. [2003], and primarily concerned the relationship between exposure dose size and plants cropping and potato tubers susceptibility to mechanical damage. Experiments in this scope were continued and extended to include, among other things, examination of processes involving germination of seed potatoes [Jakubowski 2008a] or potato tubers storage life [Jakubowski 2008b]. The research was carried out for potato varieties characterised by different earliness: Aster, Drop, Felka Bona, Velox, Rosara (very early varieties), Vineta, Gracja (early varieties), Irga (medium early variety) and Salto (medium late variety). The research results have proven that potato tuber irradiation substantially modifies subsequent progress of some ontogenesis processes in potato plants [Jakubowski 2008c]. The above-mentioned works that concern microwave radiation impact on potato plants, take into account microwaves at frequency 2.45 GHz only (the following parameters were subject to changes: power of microwave generating device and exposure time). No information regarding the impact of microwave radiation at frequencies other than 2.45 GHz on potato plants has been found in the available literature. Presented research results concerning the impact of microwave radiation at frequencies ranging within (37.5÷54.04) GHz on plant material prove positive impact of this factor on some life processes of plants. Considering the above, the researchers have chosen as the purpose of their work to examine the impact of microwave radiation at frequencies ranging within (2.45÷54) GHz on the weight of seed potato germs and on the weight of tubers in potato plants crop. The work assumes that microwave radiation at frequencies ranging within (2.45÷54) GHz will affect germination process and cropping of potato plants.

The material and methods

The research was carried out in years 2008-2009 for very early potato variety: Felka Bona (Tab. 1). In order to achieve the assumed target, the experiment was carried out in two stages. At stage I, the research involved determining seed potato germs weight, and at stage II - the crop of tubers from a single plant. Sample size in each combination was 30 tubers at each experiment stage. Seed potatoes irradiated with microwaves and check

samples were put to germination in wooden boxes at the temperature of 15-18°C for 28 days in a laboratory room with access to natural light. After 28 days the researchers measured germs weight using laboratory balance with weighing accuracy 0.02 g, and remaining seed potatoes were planted in experimental plots during the first decade of April. The crop was harvested after 65 days of plants vegetation. The weight of crop from a single plant was determined directly after the harvest. Obtained results were put through statistical analysis carried out using *STATISTICA 8.0* software package. Significance of differences was tested at the level $\alpha = 0.05$.

Two devices allowing to irradiate potato tubers with microwaves were employed in the experiment:

– microwave generator with adjustable power within range (100÷1000) W, making waves at frequency 2.45 GHz, equipped with magnetron,
– microwave generator (high-frequency signal generator: G4-141) with adjustable power output (from 0 to 20 mW), making waves at frequency ranging within (37.5-54.55) GHz, equipped with reverse wave lamp.

In case of tuber stimulation using microwave generator making waves at frequency 2.45 GHz, single tuber was placed for a specific time in a hermetic chamber with rotary bottom. In case of tuber stimulation using microwave generator making waves at frequency ranging within (37.5-54.55) GHz, single tuber was placed on Petri dish directly under an antenna forming waveguide end. Seed potato exposure parameters (irradiation time, wave frequency, and power of device generating microwaves) have been determined on the basis of published results of experiments concerning microwave radiation impact on plant material [Olchowik et al. 2002; Wójcik et al. 2004; Калинин et al. 2001, 2005; Jakubowski 2008c]. The following seed potato exposure parameters were chosen for microwave generator equipped with reverse wave lamp: microwave radiation frequency 38 GHz, 46 GHz and 54 GHz, exposure time 20 min and generator power (at output) 4 mW. The following seed potato exposure parameters were chosen for microwave generator equipped with magnetron: microwave radiation frequency 2.45 GHz, exposure time 10 s, 15 s and 20 s, and generator power: 100 W and 1000 W.

Table 1. Characteristics of seed potatoes used in the experiment

Experiment stage	Weight of seed potatoes in a sample [g]			Standard deviation [g]	Variability [%]
	Mean	Maximum	Minimum		
I	30.2	36.7	24.3	3.6	12
II	31.4	37.4	25.7	3.1	10

Source: author's own calculations

Research results and their review

Test probability level (Tables 2 and 3) in completed variance analyses has proven substantial differences between experiment combinations. Further, the researchers examined differences between mean values from individual groups. For this purpose, they applied Duncan's step by step procedure of multiple comparisons (*post-hoc*) using studentised range statistics to form homogeneous mean groups (Tables 4 and 5). Research results for germination process indicate that weight of potato tuber germs ranged from 0.645 g to 0.741 g (germs weight in check sample was 0.689 g), depending on applied microwave radiation frequency. Seed potatoes irradiated with microwaves at frequency 38 GHz were characterised by 6.4% lower germs weight compared to that of check sample. Germs weight in seed potatoes irradiated with microwaves at frequencies 54 GHz and 46 GHz was slightly higher than in check sample, but these differences were not statistically significant. Compared to check sample, statistically significant differences in germs weight were found in those combinations, where seed potatoes were irradiated with microwaves at frequency 2.45 GHz, while:

- in seed potatoes irradiated with microwaves during 15 s and 20 s (generator power: 1000 W), germs weight was approximately 2.2% higher,
- in seed potatoes irradiated with microwaves during 10 s (generator power: 1000 W), germs weight was approximately 4.2% higher,
- in seed potatoes irradiated with microwaves during 10 s, 15 s and 20 s (generator power: 100 W), germs weight was approximately 6.4% higher.

In studies involving the impact of microwave radiation on seed potato germination, Duncan's test allowed to distinguish five homogeneous groups. It should be emphasised that in completed experiment, best effect involving germs biomass growth was observed for seed potatoes irradiated with microwaves at frequency 2.45 GHz, time 10 s, generator power 100 W, where germs weight was 7.5% higher compared to check sample.

Table 2. Results of one-dimensional significance test; the impact of microwave radiation at frequencies 2.45÷50 GHz on germination of Felka Bona variety potato plants

Dependent variable	Effect and error sum squares	Degrees of freedom	Mean sum square	Value of test F	Test probability level
Free term	23.86496	1	23.86496	1230.148	0.00
Frequency	3.81961	9	0.42440	21.876	0.00
Error	5.62602	290	0.01940		

Source: author's own calculations

Table 3. Results of one-dimensional significance test; the impact of microwave radiation at frequencies 2.45÷50 GHz on cropping of Felka Bona variety potato plants

Dependent variable	Effect and error sum squares	Degrees of freedom	Mean sum square	Value of test F	Test probability level
Free term	99158752	1	99158752	51846.38	0.00
Frequency	96822	9	10758	5.62	0.00
Error	554639	290	1913		

Source: author's own calculations

Table 4. Duncan's test result for multiple comparisons - group of homogeneous mean weights of Felka Bona variety potato tuber germs

Frequency [GHz]	Time [s]	Power [W]	Germs weight [g]	Homogeneous groups				
				1	2	3	4	5
38	1200	0.004	0.645	****				
Check			0.689		****			
54	1200	0.004	0.692		****			
46	1200	0.004	0.693		****			
2.45	20	1000	0.701			****		
2.45	15	1000	0.709			****		
2.45	10	1000	0.718				****	
2.45	20	100	0.726				****	****
2.45	15	100	0.733					****
2.45	10	100	0.741					****

Source: author's own calculations

Table 5. Duncan's test result for multiple comparisons - group of homogeneous mean weights of Felka Bona variety potato tuber crop

Frequency [GHz]	Time [s]	Power [W]	Crop weight [g]	Homogeneous groups				
				1	2	3	4	5
46	1200	0.004	551	****				
54	1200	0.004	555	****				
Check			568		****			
38	1200	0.004	569		****			
2.45	20	1000	577			****		
2.45	15	1000	589				****	
2.45	10	1000	598				****	
2.45	20	100	611					****
2.45	15	100	611					****
2.45	10	100	613					****

Source: author's own calculations

Research results for cropping indicate that the weight of potato tubers crop from a single plant ranged from 551 g to 613 g (tubers weight in check sample was 568 g), depending on applied microwave radiation frequency. Seed potatoes irradiated with microwaves at frequencies 46 GHz and 54 GHz were characterised by 2.7% lower crop weight compared to that of check sample. Seed potatoes irradiated with microwaves at frequency 38 GHz proved to have crop weight slightly higher than check sample, but these differences were not statistically significant. Compared to check sample, statistically significant differences in crop weight were found in these combinations, where seed potatoes were irradiated with microwaves at frequency 2.45 GHz. In studies involving the impact of microwave radiation on seed potato cropping, Duncan's test allowed to distinguish five homogeneous groups. In the completed experiment, best effect involving potato tubers biomass growth was ob-

served for seed potatoes irradiated with microwaves at frequency 2.45 GHz, time 10 s, generator power 100 W, where tubers weight was 7.9% higher compared to check sample. In case of carried out experiment concerning the impact of microwave radiation at frequencies ranging within 38÷54 GHz on potato plants, this research may be deemed preliminary. Irradiation of seed potatoes did not give intended positive effect involving growth of seed potato germs biomass and tubers crop. Collected data also does not allow to build constructive conclusions. However, the result obtained during this experiment should not be the reason for giving up studies in this field. In the presented experiment, while selecting operation parameters for the G4-141 microwave generator and irradiation time for seed potatoes, the researchers were primarily focusing on the device technical potential, taking into account results obtained by other scientists [Hamada 2007, Olchowik et al. 1996, 2002, Wójcik et al. 2004] in their works on plants irradiation with microwaves. It should be emphasised that according to the information provided by Olchowik et al. [1997] in the above-mentioned studies, devices generating microwaves were emitting radiation with power density lower than 10 $mW \cdot cm^2$, that is under thermal impact level. Having in mind the above, one should state that next tests concerning the impact of microwaves on potato tubers should be extended to include more radiation frequencies and exposure times.

An expected effect was positive impact of microwave radiation at frequency 2.45 GHz on potato plants. Author's research results [Jakubowski 2008a] concerning irradiation with microwaves in the scope of unit doses 72.8÷200 $J \cdot g^{-1}$ (exposure time from 2 s to 60 s, microwave generator power 1000 W - for radiation frequency 2.45 GHz) proved increase in weight by 5.4%, and in quantity of seed potato germs by 2.2%. At the same time, germination time was reduced. The above research was continued with experiments involving potato plant cropping after irradiation of seed potatoes with microwaves [Jakubowski 2008d]. Result of the experiment proved positive impact of microwave radiation (exposure time 3-7 s, microwave generator power 1000 W - for radiation frequency 2.45 GHz) on potato plants cropping. Irradiation of seed potatoes allowed to extend crop by 3 to 4% and to increase mean tuber weight in crop compared to check sample. Research results presented in this work confirmed positive impact of microwave radiation at frequency 2.45 GHz on potato plants. Completed experiment allowed to find positive impact of irradiation on germination processes and potato plants cropping. The result of the experiment made it possible to verify research results obtained during former experiments in this field [Jakubowski 2008ad]. The data shown indicate that positive effect of seed potatoes irradiation, represented by increase in germs weight and higher tuber crop weight, may be obtained by applying shorter exposure times, and at the same time reducing microwave generator power. An important fact is that mean germs weights and mean weights of potato tubers crop obtained through seed potatoes irradiation lasting 10 s and 20 s, carried out at microwave generator power 100 W, are significantly higher compared to the values obtained during irradiation lasting 10 s and 20 s, carried out using microwave generator 1000 W.

Potato tuber is a highly hydrated plant part. Vibration of water molecule dipoles induced by microwave radiation gives thermal effect, which according to van't Hoff's rule and Arrhenius law affects reaction rate in biological processes. Increase in the rate of biochemical changes in a potato tuber may result in accelerated or intensified production of auxins and glutathione, which are growth activators. Formation of growth activators in potato tuber tissues initiates germination process. Additional factors affecting germs bio-

mass growth may include circulation and supplying buds with spare substances necessary to commence germination process, also connected with the rate of biochemical changes. If seed potato germination process accelerates due to microwave radiation [Jakubowski 2008a], this effect will have influence on successive plant ontogenesis stages, including vegetation period reduction or cropping size. It is also possible that microwave radiation energy received by seed potato during stimulation will be converted into other energy forms similar to those acquired by tuber through organic substances combustion. This mechanism would directly translate into processes involved in the conversion and carrying spare substances from mother tuber into other parts of the plant. This phenomenon may also affect intensity of some photosynthesis stages, supply of assimilates, the size and nature of energy conversions, and broadly understood action of enzymatic systems in a plant.

Conclusions

1. During 20 min. exposure time assumed in the experiment the researchers have not observed any positive impact of microwave radiation at the following frequencies: 38 GHz, 46 GHz, and 54 GHz on the weight of irradiated seed potato germs and on the weight of Felka Bona variety potato tubers crop.
2. Radiation at frequency 2.45 GHz, duration 10 s, and microwave generator power 100 W, induced highest biomass growth in seed potato germs and increase in the weight of Felka Bona variety potato tubers crop.

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WPŁYW PROMIENIOWANIA MIKROFALOWEGO O RÓŻNYCH CZĘSTOTLIWOŚCIACH NA MASĘ KIEŁKÓW SADZENIAKA I PLON BULW ZIEMNIAKA

Streszczenie. Celem pracy było zbadanie wpływu promieniowania mikrofalowego o częstotliwościach w zakresie (2,45÷54) GHz na wybrane procesy życiowe roślin ziemniaka. Stwierdzono pozytywny wpływ promieniowania mikrofalowego o częstotliwości 2,45 GHz na masę kiełków napromieniowanych sadzeniaków oraz na masę plonu bulw ziemniaka odmiany Felka Bona. Wpływu takiego nie stwierdzono dla promieniowania mikrofalowego o częstotliwościach 38 GHz, 46 GHz i 54 GHz.

Słowa kluczowe: ziemniak, kiełkowanie, plonowanie, mikrofale

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