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THE EFFECT OF MICROWAVE RADIATION ON THE GERMINATION PROCESS OF STORED POTATO TUBERS

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Abstract. The purpose of the present paper was to study the effect of microwave radiation on the number and weight of sprouts appearing on potato tubers after its storage. The studies included three early potato cultivars (Felka Bona, Rosara and Velox), whose tubers were radiated with microwaves with the frequency of 2.45 GHz for the period of 10, 20 and 60 s. Results of the experiment show that microwave radiation significantly modifies the germination process of the stored potato tubers.

Key words: potato, microwave, storage, germination

INTRODUCTION

Germination of potato tubers is above all dependent on the date when their natural rest time finishes. The intensity of germination is especially affected by temperature, humidity and the composition of the atmosphere during storage. The natural rest period of potato tubers is mainly influenced by the cultivar and the climatic conditions during the plant's vegetation but the beginning of the germination process is affected – apart from the cultivar – by the degree of maturity of the tubers and the conditions of their storage [Kubicki 1973, Nowotny 1972]. From the point of view of agricultural practice, germination of the stored potato tubers is a negative phenomenon. In the case of tubers intended for eating, industrial purposes or for fodder, this leads to mass losses of the stored yield. In the case of seed-potatoes, it causes the formation of breakable and elongated etiolated sprouts. A positive effect of magnetic and electric fields was proved by Pietruszewski [2002], Pietruszewski and Kornarzyński [2002], Kornarzyński and Pietruszewski [2005] and Marks and Szecówka [2010]. It follows from the Author's studies [Jakubowski 2008a] that irradiating potato tubers with microwaves causes increased number and mass of seed-potato sprouts appearing during subgermination. A similar phenomenon was observed for potato tubers (irradiated with microwaves

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before being placed in a storage room) after their storage [Marks and Jakubowski 2006, Jakubowski 2008b]. However, those studies established only the weight loss of the stored potato tubers caused by the germination process. Due to the fact that microwave radiation – through increasing the degree of infection by *Rhizoctonia solani* Kühn [Marks et al. 2005] – decreases the losses of the stored potato tubers, it is also justified to find out the effect of this radiation on their germination. Considering the above, the purpose of the paper was formulated as examining the effect of microwave radiation on the number and weight of the sprouts appearing on potato tubers after the period of their storage.

THE SCOPE OF THE STUDY. MATERIAL AND METHODS

The experiment was conducted in the years 2006–2008 on three early potato cultivars: Felka Bona, Rosara and Velox. The experiment used fractioned potato tubers with the unit weight within the range of 35–45 g in the number of 150 for each cultivar. The tubers were chosen at random and the size of the sample was based on the indications by Stanisz [2005]. The weight of each tuber was determined after the harvest. 30 tubers for each experimental combination were irradiated with microwaves in the following times: 10, 20 and 60 s. The exposure time was established on the basis of the Author's preliminary studies [Jakubowski 2008b]. A control sample was considered in the experiment for each cultivar. A device with the power of the source of 100 W generating microwaves with the frequency of 2.45 GHz was used. A single tuber was placed in a tight chamber equipped with a rotary bottom and a precise time switch. The actual full doses of microwave radiation – considering power losses – ranged between 150 and 9000 J (with the assumed parameters of the generator's work considering no losses, the complete doses of microwave radiation would range from 1000 to 60 000 J) and the real unit doses considering the tuber weight were within the range from 3.33 to 257.14 $J \cdot g^{-1}$. The thermal effect of microwaves (in theoretical doses) on the irradiated potato tuber can be determined by the increase of its temperature according to the relation provided by the Author [Jakubowski 2009a, b]. Changeability of the tuber weight did not exceed 9% in any of the years (tab. 1).

Directly after the exposure, the samples were placed and stored in wooden boxes in cold store at the temperature of 5–6°C with the humidity of 90–95% for the period of 7 months. Such a way of storing ensured uniform conditions of heat and tuber weight exchange with the environment. After storage, the number and weight of the sprouts was established in each tuber. The experiment used laboratory scales with the accuracy of 0.02 g. Results obtained during the studies were statistically analyzed using STATISTICA 8.0 at the level of significance of $\alpha = 0.05$. Results related to the number of sprouts are measurable variables with step response, which is a prerequisite to use non-parametric tests. The Kruskal-Wallis one-way analysis of variance by ranks was applied as a non-parametric equivalent of variance analysis for many trials with single classification followed by post-hoc tests, which are multiple comparisons of mean ranks for the studied samples. Results concerning the sprout weight were analyzed using a factor analysis of variance considering the main effects (without interaction effects)

Table 1. Basic statistics concerning the weight of potato tubers used in the experiment
Tabela 1. Podstawowe statystyki dotyczące masy bulw ziemniaka użytych w doświadczeniu

Cultivar and year of studies Uprawa i rok badań	Tuber weight in a sample Masa bulw w próbie (g)			Standard deviation Odchylenie standardowe (g)	Variability coefficient Współczynnik zmienności (%)
	mean średnia	minimum	maximum		
Felka 2006	38.9	35.0	44.2	2.9	7.7
Velox 2006	38.6	35.0	44.5	2.8	7.4
Rosara 2006	39.0	35.3	44.8	2.9	7.5
Felka 2007	38.9	35.0	44.2	3.0	7.9
Velox 2007	39.9	35.0	45.0	3.4	8.5
Rosara 2007	39.0	35.3	44.8	3.0	7.8
Felka 2008	40.1	35.0	45.0	3.5	8.8
Velox 2008	38.8	35.0	44.5	2.8	7.4
Rosara 2008	37.9	35.0	44.8	3.1	8.2

between the studied variables. Groups of homogenous variables were established using the procedures of multiple comparisons with Duncan's test.

RESULTS AND DISCUSSION

Tables 2–7 present results of variance analysis and post-hoc tests concerning the effect of microwave radiation on the process of germination in the stored potato tubers determined by the number and weight of sprouts. The studied year did not have any significant effect on the germination process of the stored potato tubers.

Table 2. The effect of one-dimensional test of significance, the effect of the studied year, cultivar and microwave radiation time on the weight of sprouts of stored potato tubers
Tabela 2. Wpływ jednowymiarowego testu istotności, roku badań, odmiany i czasu promieniowania mikrofalowego na masę pędów przechowywanych bulw ziemniaka

Independent variables Zmienne niezależne	Sum of squares Suma kwadratów	Number degrees of freedom Liczba stopni swobody	Mean square Średnia kwadratów	Value of F test Wartośc testu F	Value of test probability Wartość prawdopodobieństwa testu
Free word Wolny wyraz	17045.33	1	17045.33	2330.342	0.000
Year of studies Rok badań	3.31	2	1.66	0.227	0.797
Potato cultivar Uprawa ziemniaka	558.77	2	279.38	38.196	0.000
Exposure time Czas ekspozycji	286.03	3	95.34	13.035	0.000
Error Błąd	7841.16	1072	7.31		

A significant effect was found for the potato cultivars and times of microwave radiation considered in the experiment (tabs. 2 and 5). It follows from the data included in tables 3 and 6 that tubers of Rosara and Velox cultivars germinate during storage in a similar manner. The information presented in tables 4 and 7 allow for the statement that irradiating potato tubers with microwaves for the period of 10 s and 20 s caused increased sprout weight, with the period of 10 s also causing an increased number of sprouts. Under the effect of microwave radiation (acting for 10–20 s) in the present experiment the weight of the sprouts of a potato tuber increased on average by nearly 34%, and the number of sprouts by 16% (control sample = 100%).

Table 3. The result of Duncan's test for homogenous groups of variables; the effect of potato cultivar on the weight of sprouts of stored potato tubers
Tabela 3. Wynik testu Duncana dla jednorodnych grup zmiennych; wpływ odmiany ziemniaka na masę pędów przechowywanych bulw ziemniaka

Cultivar – Odmiana	Weight – Masa (g)	Homogenous groups Grupa homogeniczna	
		1	2
Felka Bona	2.97		****
Velox	4.33	****	
Rosara	4.62	****	

Table 4. The result of Duncan's test for homogenous groups of variables; the effect of microwave radiation time on the weight of sprouts of stored potato tubers
Tabela 4. Wynik testu Duncana dla jednorodnych grup zmiennych; wpływ czasu promieniowania mikrofalowego na masę pędów przechowywanych bulw ziemniaka

Exposure time Czas ekspozycji (s)	Weight – Masa (g)	Homogenous groups Grupa homogeniczna	
		1	2
Control – Kontrola	3.33	****	
60	3.65	****	
20	4.25		****
10	4.66		****

A higher number of sprouts among the irradiated seed-potatoes testifies to a greater number of actively germinating eyes. A decreasing trend can be noticed between the sprout weight, the number of sprouts and the increase of the time of microwave radiation. Such a result is probably caused by the thermal effect of the microwave which can lead to plants' damaged cell membranes and, further on, to inhibited life processes. According to Nowotny [1972], ionizing radiation (Roentgen radiation and radiation of radioactive cobalt CO^{60}) affects potato tubers like an inhibitor of germination.

In the case of microwave radiation time of 10–20 s, it was possible that heating the tubers did not cause damage to the cell membranes but it could contribute to the shortening or interruption of the physiological rest and beginning the germination process. In the case of the effect of electromagnetic fields on the seed material of certain cultivated plants, similar effects were obtained by Namba et al. [1995], Rochalska [1997, 2001], Sasao et al. [1998] and Carbonell et al. [2000]. However, it should be remarked that in the case of the experimental results described by the aforementioned authors, the thermal effect of electric and magnetic fields was not as significant as in the case of microwave radiation of potato tubers.

Table 5. The result of the post-hoc test for the Kruskal-Wallis variance analysis; the effect of the year of studies. potato cultivar and radiation time on the number of sprouts of the stored potato tubers
Tabela 5. Wynik testu post-hoc dla analizy wariancji Kruskala-Wallisa; wpływ roku uprawy, odmiany ziemniaka i czasu promieniowania na liczbę pędów przechowywanych bulw ziemniaka

Qualitative predictor Wartość oczekiwana		Sum of ranks Suma rangi	Number of sprouts Liczba pędów	Test value by Kruskala-Wallisa Wartość testu Kruskala-Wallisa	Value of test probability Wartość testu prawdopodobieństwa
Year of studies Rok badań	2006	190424.0	2.6	H = 0.85 (insignificant – nieistotny)	p = 0.653
	2007	195524.5	2.7		
	2008	197791.5	2.8		
Potato cultivar Odmiana ziemniaka	Felka Bona	170921.5	2.3	H = 25.33	p = 0.000
	Velox	208243.0	2.9		
	Rosara	204575.5	2.9		
Exposure time Czas ekspozycji	control – kontrola	133847.0	2.5	H = 12.92	p = 0.000
	60 s	158440.0	2.6		
	20 s	148976.5	2.7		
	10 s	142476.5	2.9		

A potato tuber is a strongly hydrated material and the microwaves absorbed by it (especially those with the frequency of 2.45 GHz) cause vibrations of water dipole and, as a consequence, increased temperature. During the stimulation of the seeds of cultivated plants, such a phenomenon occurs to a limited extent. However, it should be emphasized hat the energy of the electromagnetic field, which is a sum of the electric and magnetic fields (and hence also microwave radiation) is described by the same physical values: the Poyinting vector and Maxwell's equations [Czarczyński 2003].

The above justifies the statement that the phenomena similar to the above described effect of electromagnetic fields on plant seeds can occur in the course of the microwave heating of potato tubers, especially in the sphere of nonthermal effect of microwaves. The nonthermal character of the effect of nonthermal radiation on live organisms is observed especially in the millimeter range of the wave lengths. The frequency of free vibrations of certain microparticles of biological materials are within the frequency corresponding to the range of millimeter waves. This means that microwaves can affect plants through resonance effects, which can in turn lead to conformation changes of particles and thus affect biochemical processes taking place in a cell [Weeb 1983, Belajew and Krarchenko 1994].

Table 6. The result of the post-hoc test for the Kruskal-Wallis variance analysis; the effect of potato cultivar on the number of sprouts of the stored potato tubers
Tabela 6. Wynik testu post-hoc dla analizy wariancji Kruskala-Wallisa; wpływ odmiany ziemniaka na liczbę pędów przechowywanych bulw ziemniaka

Qualitative predictor Wartość oczekiwana	Potato cultivar and rank value Odmiana ziemniaka i wartośc rangi (R)		
	Felka Bona – R:474.78	Rosara – R:578.45	Velox – R:568.27
Felka Bona		0.000	0.000
Rosara	0.000		1.000
Velox	0.000	1.000	

Table 7. Result of the post-hoc test for the Kruskal-Wallis variance analysis; the effect of microwave radiation time on the number of sprouts of the stored potato tubers
Tabela 7. Wynik testu post-hoc dla analizy wariancji Kruskala-Wallisa; wpływ czasu promieniowania mikrofalowego na liczbę pędów przechowywanych bulw ziemniaka

Qualitative predictor Wartość oczekiwana	Exposure time and rank value Czas ekspozycji i wartość rangi (R)			
	control – kontrola R:495.73	10 s R:586.81	60 s R:527.69	20 s R:551.76
Control – Kontrola		0.004	1.000	0.221
10 s	0.004		0.166	1.000
60 s	1.000	0.166		1.000
20 s	0.221	1.000	1.000	

In the studies by Marks and Jakubowski [2006], acceleration of the germination process after irradiating potato tubers with microwaves was explained by the increase in their temperature and acceleration of biochemical changes taking place in them. It is a fact that biochemical processes taking place in plants, especially the speed of those reactions, are dependent on the temperature. According to the Author, however, in the present experiment it is not only the thermal effect of the absorption of microwaves by potato tubers which will play an important role. The result of the experiment, where the radiation time of 10 s affected increased weight and number of sprouts, can justify the statement that the process of germination of stored potato tubers is affected by microwaves both through the thermal and athermal effects. According to Dewiatkow [1987], the thermal effect takes place when – as a result of absorption of the energy of electromagnetic radiation – the temperature of the object increases by more than 0.2 K. However, it should be emphasized that the thermal effects are also related to the proportion of the size of the irradiated body to the wave length as well as to the direction of the electric field vector [Karimova 1984, Shmigel et al. 1984].

Results of the Author's earlier studies [Jakubowski 2009ab] indicate that in the present experiment and with the exposure time of 10 s (after considering the unit dose of microwaves), both thermal and athermal effects occurred in the irradiated potato tuber. As mentioned in the introduction, irradiating potato tubers before their storage causes a decrease in the degree of their infection by *Rhizoctonia solani* Kühn. At the same time, this method affects the germination processes through increasing the weight and number of potato tuber sprouts. In such a case, the available inhibitors of germination can be applied [Czerko 2010, Daniels-Lake et al. 2005] with a reservation, however, that the occurrence of the possible interaction between the dose of microwaves and the applied inhibitor of germination of the stored potato tubers should be studied.

CONCLUSIONS

1. Irradiating potato tubers with microwaves before storage for the periods of 10 s and 20 s causes an increase of the sprout weight, while the period of 20 s also causes an increase in the number of sprouts after the storage period.
2. The studies found out a similar reaction to microwave radiation – established by the weight and number of sprouts in a tuber – of Rosara and Velox cultivars of potato, as different from the cultivar of Felka Bono.

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WPŁYW PROMIENIOWANIA MIKROFALOWEGO NA PROCES KIEŁKOWANIA PRZECHOWYWANYCH BULW ZIEMNIAKA

Streszczenie. Celem pracy było zbadanie wpływu promieniowania mikrofalowego na liczbę i masę pędów pojawiających się na bulwach ziemniaka w czasie przechowywania. Badania obejmowały trzy wczesne odmiany ziemniaka (Felka Bona, Velox i Rosara), których bulwy poddano emisji mikrofal o częstotliwości 2,45 GHz w czasie 10, 20 i 60 s. Wyniki eksperymentu wskazują, że promieniowanie mikrofalowe znacząco modyfikuje proces kiełkowania przechowywanych bulw ziemniaka.

Słowa kluczowe: ziemniak, mikrofale, przechowywanie, kiełkowanie

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