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IMPACT OF UV-C RADIATION ON THE INFESTATION DEGREE OF THE STORED POTATO TUBERS WITH *RHIZOCTONIA SOLANI* KÜHN

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ABSTRACT

Within 2012-2014 two independent storage experiments aiming at determination of the UV-C radiation impact on the infestation degree of potato tubers with *Rhizoctonia solani* Kühn were carried out. Potato tubers were radiated in the chamber equipped with a UV-V 15 radiator located over the bottom of a chamber from 0.4 to 1.0 m over the ground using the exposition time within 1 to 60 minutes. Four edible potato varieties with a varied degree of earliness and varied fitness for use and culinary utility of the following tubers: Lord, Owacja, Vineta and Jelly, were used in tests. It was determined that radiation of Owacja tubers before storing caused reduction of Rhizoctonia canker in comparison to the control sample.

Introduction

Losses caused by pathogenic micro-organisms are one of the reasons why potato tubers are affected by mass reduction when stored. A disease, which often occurs on potato plants in all stages of their growth is Rhizoctonia canker caused by fungi from the species of *Rhizoctonia solani* Kühn (a perfect stadium *Thanathephorus cucumeris*). These fungi are responsible for decay of seed potato sprouts, rotting of stem bases, pock-marking of tubers and they are the source of a daughter plant infection (Van Emden, 1965; Lehtonen et al., 2008ab, Jakubowski, 2010). Pock-marking is one of the disease forms which occur on the potato tuber skin. Infected tubers are covered with dark sclerotium (a surviving form of a pathogen), which are formed when potato matures; after harvesting they remain on the tuber periderm during the storage period. Main agrotechnical methods of fighting with Rhizoctonia canker include chemical treatment of seed potatoes and protection of a plantation with the use of fungicide preparations. However, it should be emphasised that such methods of plant protection against this pathogen are not recommended in case of organic crops (Lenc, 2006). The use of physical methods, with regard to the stored potato tubers, is a solution which includes rigorous requirements of organic agriculture. Results of the research carried out by Martens et al. (1992) and Castro et al. (1993) indicate that the pulse electric field effect on *Saccharomyces cerevisiae* fungi reduces their population. Similar effects were obtained by Marks (2005ab), who investigated the impact of the pulse electric

field and variable magnetic field on *Alternaria solani* fungi growth in the stored potato tubers of Drop, Irga and Salto potato tubers. Results of the research carried out by the same author (Marks et al., 2005c; 2006) prove that both effect of the electric field as well as the magnetic one and microwave radiation (Jakubowski, 2010) decreases storage losses of potato tubers of Drop, Irga, Salto, Felka Bona, Rosara and Velox varieties caused by Rhizoctonia canker. The results presented above show efficiency of the effect of the mentioned physical methods on some pathogens of potato tubers. Therefore, searching for and investigating the impact of many physical methods, which limit development of storage diseases of potato, is reasonable.

Ultraviolet radiation is one of the components of the solar spectrum, which reaches the Earth. Ultraviolet (UV) in relation to the wave length and effects on living organisms occurs in three bands (scopes): UV-A (315-400 nm), UV-B (280-315 nm), UV-C (100-280 nm). In spectroscopy, division of radiation is slightly extended: border, far, medium and close (respectively: 10-121, 122-200, 201-300, 301-400 nm). It should be emphasised that the above mentioned divisions (scopes) are of contractual nature (Lucas et al., 2006).

Impact of ultraviolet radiation on the biological material (soy August variety) was the subject of the research carried out by Szwarc and Skórska (2007). The applied UV-B radiation reduced intensity of photosynthesis, the content of chlorophyll and negatively influenced the increase and biomass of overground parts. Defence reactions in the form of the increased synthesis of flavonoids and increased acitvity of antioxidizing enzymes (peroxidase and catalase) were reported. UV radiation in C band was used in the processes of food sterilization (Corales, 2012) namely as a method of plant protection (patent US 2009/0272029 A1). Páez et al. (2011) used a physical method for fighting with seeds mycobiots and Korobczak et al. (2005) used radiation of potato plants with UV-C in order to cause the symptoms of abiotic stress. Błażejak et al. (2011) carried out research on the use of ultraviolet radiation for obtaining mutants *Gluconacetobacter xylinus*, which were then used to carry out biotransformation of glycerol in DHA (the best of mutants synthesized 18.00 mg DHA·cm^{-3}, that is by 32% of DHA·cm^{-3} more than the parent graft). With reference to potato, the impact of UV-C radiation was investigated in the aspect of its impact on seed potatoes of Jelly variety and the further course of plant ontogenesis (Jakubowski and Pytlowski, 2013). A significant impact of radiation became visible in the development of the overground part of potato. Taking into consideration the above, the objective of the experiments, which were carried out, was to determine the impact of UVC radiation on the infestation degree of the stored potato tubers with *Rhizoctonia solani* Kühn.

The scope of paper and methodology of research

Within 2012-2014 two independent storage experiments aiming at determination of the UV-C radiation impact on the infestation degree of potato tubers with *Rhizoctonia solani* Kühn were carried out. The experiment differentiated the origin of material for research and the used potato variety. The common feature of experiments was the use of potato tubers as a material for research and the use of UV-C radiation towards the material. Four edible potato varieties with a varied degree of earliness and varied usefulness and culinary utility of tubers were used in the experiment: Lord (a very early variety useful for production of canned food, vegetable salads and frozen products, hard), Owacja (an early variety, of general usefulness, slightly hard and floury), Vineta (an early variety useful for production of

canned food, vegetable salads and frozen products, hard) Vineta (an early variety, useful for production of canned food, vegetable salads and frozen products, hard) and Jelly (a middle late variety, of general utility, slighlty hard). Degree of infestation with *Rhizoctonia solani* Kühn was determined through a percentage of infestation with sclerotium (pock-marking) of the potato tuber periderm acc. to methodology of IHiAR [Plant Breeding and Acclimatization Institute] (Roztropowicz, 1999). Infestation was determined through the reverse scale 9º (9º – not infected, 1º – infestation above 25% of the skin surface). Potato tubers were radiated in a chamber equipped with TUV UV-C 15 W type radiator (intensity of linear radiation 253.7 nm in the distance of 1 m from the lamp – 0.42 $W \cdot m^{-2}$, total linear energy stream 253.7 nm=4.0 W) located over the bottom of the chamber at the height of 0.4 to 1.0 m using the exposition time within 1 to 60 minutes. (table 1). In the experiment no. I material for research came from a crop under the plastic tunnel. The methodology of agrotechnological treatments and the arrangement of experiment was the same as the one presented in the author's paper concerning the impact of ultraviolet on the growth and yield of potato plant (Jakubowski and Pytlowski, 2013). Experiment (no. I) provided for radiation of tubers before planting, evaluation of the infestation degree with rhizoctonia canker directly after harvesting and after storing. In experiment no. II the research material came from field cultivations, where correct rules of agrotechnology designed for potato plants were applied. Experiment (no. II) provided for the evaluation of the infestation degree of potato tubers with rhizoctonia canker directly after the harvest of yield, radiation of tubers before their storing and then another evaluation of infestation after storing. In both experiments in the subsequent years of the research, a possibility of modification of working parameters of a chamber within the scope of the exposition time and the height of a radiator was taken into account. Combinations in experiments included a control sample. The obtained results were subjected to statistical interpretation with the use of STATISTCA 10 at the level of significance $\alpha=0.05$. The analysis of variance preceded by the research on the regularity of the distribution in samples (Kolmogorov-Smirnov test) and the uniformity of variance (Levene's test) was carried out. Multiple comparisons were made with the use of Duncan's range test based on the order statistics. On account of different origin of the research material and the admitted possibility of modification of working parameters of the chamber, no statistical differences between the years and experiments were determined.

Table 1
Arrangement of experiments within 2012-2014

Symbol of experiment		Year of realization	Characteristics of experiment				
			Variety	Sample size (items) in combination (for variety)	Time of radiation (min)	Height of radiator (m)	Date of radiation
I	A	2012-2013	Jelly	30(120)	0*, 1, 10, 60	0.7	before planting
	B	2013-2014			0*, 5, 15, 30	0.4	
II	A	2012-2013	Lord Owacja Vineta	100(1000)	0*, 1, 10, 30	0.4, 0.7, 1.0	before storing
	B	2013-2014	Owacja	100(500)	0*, 15, 20	0.5, 0.6	

*control sample

Research results and discussion

Results of Kolmogorov-Smirnov test proved compliance of the empirical distribution of samples with a regular distribution. Levene's test confirmed uniformity of variance in the investigated samples. The above test authorized the use of a multi-factor analysis of variance including interaction effects. In all the researched combinations of the experiment a higher degree of infestation of potato tubers with rhizoctonia canker after storing compared to evaluation made before placing them in a freezer was determined.

In case of experiment no. I, where material from cultivation under plastic foil with reference to the control sample, no statistically significant impact of radiation of seed potatoes on the degree of infestation of the stored potato tubers with rhizoctonia was reported (insignificant value of Snedecor's test F=3.45). In experiment no. Ia 10 min. – radiation time, compared to the control, caused decrease of the infestation degree with rhizoctonia by average 2.2%. In experiment IB the height of a radiator and time of its operation was corrected. The effect of changes of the chamber operation parameters was reflected in a lower degree of infestation with rhizoctonia (by average 2.5%) at the radiation time of 15 minutes. (referred to the control sample).

In the part of the experiment (no.II), where the research material came from field cultivations, a significant impact of quality predictors, accepted in the experiment, on the investigated dependable variables was presented (Table 2). Post-hoc tests which were carried out in the experiment IIA proved that, Owacja variety reacted positively (table 3 and 4) on 10 minute UV-C radiation at the height of a radiator of 0.4 and 0.7 m (a lower by 5.5%, degree of infestation of radiated tubers, at the average for both heights of a radiator, in comparison to the control sample was reported).

In experiment IIB (where Owacja variety was investigated) the height of a radiator and the time of its operation were corrected which resulted in a significantly lower degree of infestation with rhizoctonia (average by 5.3%) at 15 min. radiation (with reference to the control sample). In this part of the experiment, it was not confirmed that the height of a radiator significantly influenced the degree of potato tubers infestation with rhizoctonia (table 4 and 5).

Table 2

Results of analysis of variance for part of experiment IIA; impact of variety, UV-C radiation time and height of radiator on degree of tubers infestation with rhizoctonia after storing

Quality predictor	Sum of squares	Number of degrees of freedom	Mean square	Value	
				of F Snedecor test	of test probability
Absolute term		0			
Variety	39.92	2	19.96	15.23	0.000
Time	32.98	2	16.49	12.59	0.000
Height	21.61	2	10.80	8.25	0.001
Error	382.48	2994	0.13		

Table 3
Arrangement of variable homogeneous groups; reaction of investigated potato varieties radiated by UV-C on degree of tubers infestation with rhizoctonia (after storing)

Variety	Degree of infestation	Homogeneous groups	
		1	**2**
Lord control	7.6	****	
Lord	7.6	****	
Owacja control	7.8	****	
Vineta control	7.8	****	
Vineta	7.8	****	
Owacja	8.3		****

Table 4
Results of analysis of variance for part of experiment IIB; impact of variety and height of radiator on degree of Owacja tubers infection with rhizoctonia after storing

Quality predictor	Sum of squares	Number of degrees of freedom	Mean square	Value	
				of F Snedecor test	of test probability
Absolute term		0			
Time	6.40	1	6.40	9.50	0.003
Height	2.50	1	2.50	3.71	0.061
Error	31.00	498	0.06		

Table 5
System of variable homogeneous groups; impact of radiation time on degree of infestation with Rhizoctonia canker of Owacja variety tubers after storing

Time of radiation	Degree of infestation	Homogeneous groups	
		1	**2**
Control	7.6	****	
20 min	7.7	****	****
15 min	8.0		****

Here it should be emphasized that although the value of Snedecor's test (F=3.71), which determined the effect of the grouping variable (the radiator height) on the infestation with rhizoctonia proved to be insignificant (p=0.0603), the value of the test probability is very close to the border value of the assumed level of significance α. The results obtained within 20 minutes of radiation time, may be interpreted explicitly since the so-called "group over-lapping" takes place.

The result of the experiments, reserving the variability of the origin source of the material for research, allows formulation of general statements:

– the time of UV-C radiation with is significant (before planting, before storing),
– the reaction of plants to UV-C radiation may be a varietal property,
– it is possible that the effect of interaction between the UV-C radiation time and the height of a radiator over the bottom of a chamber is crucial.

According to Pilarski et al. (2012) a solar spectrum which reached the surface of the Earth's atmosphere covers a very broad spectrum of radiation (from several hundred to

several thousand nm). This radiation, when it is getting through atmosphere, is absorbed and dispersed as a result of reaction with atoms, particles, aerosols and dust (natural and anthropogenic ones) included therein. Molecular oxygen, as well as in the atomic form or in the form of ozone, absorbs ultraviolet radiation which results in the changes of a spectrum, which gets to the Earth surface. The spectrum is devoid of almost entire UV-C and UV-B radiation and includes insignificant amounts within UV-A. The above shows that UV-C radiation, used for the needs of agricultural demands, may be produced in principle exclusively by artificial sources. The plant produced in itself protecting mechanisms against harmful effect of UV. This role is played by flavonoids (flavonols and anthocyanins) which reduce UV radiation transmission through epidermis at the simultaneous permeability of PAR radiation. The effect of screening is protection of a photosynthetic apparatus and plant structures against DNA damages. Moreover, a protective role is played by various epidermis forms, e.g. hair may disperse up to 70% of the UV radiation. Pigments (except for flavonoids) which protect against harmful UV effect are carotenoids which have antioxidizing properties and which extinct active form of oxygen (Tevini, 1993; Robin et al., 1994; Cockeel et al., 1999; Pilarski et al. 2012).

Radiation in UV-C band consists in waves with the length of 100-280 nm. Waves with length of 100-200 nm, the so-called Shumann's rays, are not biologically active because they are absorpbed by oxygen and particles of water steam. This limitation causes that biologically active ultraviolet in C band is represented by waves with length of 200-280 nm but the highest activity is within the range of 250-270 nm (254 nm). This information is crucial because when the experiment is carried out, it allows narrowing the research scope in the described object. In the available literature no information on the possibility of absorption (as well as adsorption) of UV radiation by potato tubers was found out. On this stage of research, it may be assumed that in case of plant material a similar mechanism of assimilation of electromagnetic wave as the one described in physiotherapy issues may occur (Poon et al., 2005). Therefore, it shall be assumed that radiation within 184.9-290 nm (the scope applied in phototherapy) gets through a potato tuber up to the depth of 2 mm (namely as deep as periderm and pith which adheres to it). Moreover, the radiated object must comply to Grotthuss-Draper's law according to which a photochemical transformation in the reacting system may be caused only by radiation absorbed by this system (Lechowski and Białczyk, 2003; Negash and Björn, 1986; Worrest and Häder, 1997). Effect of ultraviolet on biological material causes a photochemical reaction (photosynthesis, photolysis, oxidization and reduction).

From the point of view of the researches which were carried out, a photochemical effect in the form of photoisomeration seems to be significant. This reaction in case of a potato tuber, consist in transformation of chemical compounds (organic pigments as flavonoids) into its another isomer as a result of photons effect (Reddivari et. al., 2007; Keutgen et al., 2014). Although isomers are chemical compounds with identical total molecular formulas, as compounds they were built of, they differ with order and manner of atomic bonds as well as they may be distributed differently. The above discussions should be assumed as hypothetical and treated as a presumption to carry out further research in this field. A reasonable justification of the obtained research result (reduction of the degree of infestation with rhizoctonia) is accepting a biophysical nature of the phenomenon in the form of UV-C radiation effect on the biological material. UV-C radiation with the wave length 253.7 nm has sterilizing and disinfecting properties. This effect is visible in particular when referred

to bacteria, viruses and fungi through the effect which leads to DNA chains damages (Kowalski, 2009). It is probable that potato periderm exposition to ultraviolet in C band may reduce *Rhizoctonia Solani* Kühn fungi population and thus reduce the pock-marking of tubers caused by them.

Conclusions

1. No significant impact of radiation of seed potatoes before their planting on the degree of infestation of potato tubers with rhizoctonia canker before their storing was reported (experiment with symbols IA and IB).
2. From among the investigated potato tubers, only Owacja variety reacted positively with lower infestation with rhizoctonia of the stored tubers on UV-C radiation (experiment with symbols IIA and IIB).

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WPŁYW PROMIENIOWANIA UV-C NA STOPIEŃ PORAŻENIA PRZECHOWYWANYCH BULW ZIEMNIAKA PRZEZ *RHIZOCTONIA SOLANI* KÜHN

Streszczenie. W latach 2012-2014 przeprowadzono dwa niezależne doświadczenia przechowalnicze mające na celu określenie wpływu promieniowania UV-C na stopień zainfekowania bulw ziemniaka przez *Rhizoctonia solani* Kühn. Bulwy ziemniaka naświetlano w komorze wyposażonej w promiennik UV-C 15 W usytuowany nad dnem komory na wysokości od 0,4 do 1,0 m stosując czas ekspozycji w zakresie od 1 do 60 min. Jako materiału do badań użyto czterech jadalnych odmian ziemniaka o różnym stopniu wczesności oraz różnej przydatności użytkowej i kulinarnej bulw: Lord, Owacja, Vineta i Jelly. Stwierdzono, iż naświetlanie przed przechowywaniem bulw odmiany Owacja przyczyniło się do zmniejszenia porażenia rizoktoniozą w porównaniu z próbą kontrolną.

Słowa kluczowe: ziemniak, przechowywanie, rizoktonioza, UV-C