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ASSESSMENT OF POTATO TUBER PARENCHYMA OF SEED-POTATOES IRRADIATED WITH MICROWAVES

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Summary. The purpose of the work was to examine the impact of microwave radiation on formation of potato tuber parenchyma defects (inhomogeneity, discolourations, glassiness, rusty dark spots and hollow hearts). Research, which was carried out in 2008-2010 included very early potato cultivars: Felka Bona, Rosara, Velox and Lord. A device operating with the power of 100 W, generating microwave radiation of 2.45 GHz frequency was used in the experiment. The research results within radiation times accepted for the experiment, do not prove a significant influence of microwaves on formation of the mentioned internal potato tuber defects.

Key words: potato, potato tuber, parenchyma defects, microwaves

Introduction

Pathogens and pests and the system of some abiotic factors (mainly climatic and soil conditions) in the vegetation period may lower the yield of potatoes of as much as 70% depending on the intensification degree of their occurrence [Beukema 1990; Leszczyński 1994]. There may be two types of negative influence of diseases and pests as well as abiotic factors impact during the vegetation period on potato plantations. These are: damage to assimilation surface of plants, which results in the decrease of a total yield of potato tubers and the simultaneous, from the moment of tuberisation, decrease in the quality of the obtained crop. The highest quality requirements of the edible potato market cause that in the process of co-packing all defective tubers should be removed from the collected crop. A potato producer, who selects the crop before preparation of goods for sale, is obliged to reject defective tubers and qualify them as unuseful or of worse quality. It is especially important at the edible potato production, where the appearance of tubers is assessed by a buyer and influences a consumer's decision. As it was mentioned above, potato tuber defects may be caused by viruses, bacteria, fungi, pests or may be determined by incorrect agrotechnology and disadvantageous soil and climate conditions during the vegetation period [Haynes 1998].

The following constitute frequent potato tubers parenchyma defects, which are caused by abiotic factors: inhomogeneity, discolouration, glassiness, rusty brown spots or hollow hearts [Nowacki 2006; 2007]. The above mentioned internal defects are difficult to recognise without permanent infraction of the potato tuber structure [Cabezas-Serrano et al. 2009; Mizrach 2008; Laerke et al. 2002] (this fact may influence the producer's assessment during a standard quality selection of tubers). Inhomogeneity of parenchyma is formed at a varied consistency of outer and inner part of a potato tuber (it may occur as well at a high marking of a fibre-vascular bundle in the plant tissue).

The oxidation processes of ferric compounds and chlorogenic acid caused by occurrence of oxygen in the air (non-enzymatic processes) or reactions related to mixing of substrates, which result from cell defects (enzymatic processes) – enzyme, which is released during the reaction modifies colour of the tissue- these may be the reasons for potato tuber parenchyma discolourations. Glassiness is a defect which may occur in case of a secondary growth of a potato tuber. In case of a secondary growth, starch is released from the parent tuber and the release starts near the proximal end of a potato. The glassiness defect is reported when after cutting a tuber, which underwent the secondary growth, its tissue has a watery and transparent or spongy structure. Rusty brown spots is a defect which manifests itself inside tubers in the form of irregular rusty brown or dark brown spots, which are a cluster of necrotic cells. Whereas, hollow hearts manifest themselves mainly inside big tubers in the form of hollow tunnels separated from the parenchyma with corked tissue [Smit et al. 1988; Głuska 2002; Krzysztofik 2003; Sadowski 2004].

Quality defects are significant for producers and food-processors because they decide on the suitability of the plant material for storing and further for processing and consumption. The above-mentioned potato tuber parenchyma defects, according to Ratuszniak [1994], may considerably decrease or even totally disqualify such a raw material in case of its processing into crisps, fries or dried potatoes. Results of Marks et al.'s works [2005] and the author's works [Jakubowski 2010] indicate a positive influence of some physical methods (magnetic and electric field and microwave radiation) on cropping and accompanying processes of potato tubers storing. If microwave radiation influences the changes in the structure of potato crops, then it is reasonable to examine this influence also on the occurrence of inner defects of potato tubers. Pot experiment, carried out under a plastic tunnel (with the use of a very early potato cultivar Felka Bona), allowed to determine that microwave radiation partially eliminates influence of the abiotic factor, that is, drought [Jakubowski 2009] (rusty brown spots and hollow hearts result from, inter alia, uneven moisture of soil). No information was found on the influence of microwave radiation on formation of inner defects of potato tubers in the available literature. It was assumed that irradiation of seed - potatoes with microwaves may influence the formation of potato tubers parenchyma defects caused by physiological disturbances in a descendant plant. The purpose of the work was to determine the impact of microwave radiation on formation of potato tuber parenchyma defects, such as inhomogeneity, discolouration, glassiness, rusty dark spots and hollow hearts. Positive results of research may be useful in the production of a potato of wide range of food industry purposes.

The scope of work and the accepted method of research

The research was carried out in 2008-2010. Four very early potato cultivars (Felka Bona, Rosara, Velox and Lord) were the object of the research. Two times of microwave radiation were included (10 and 20 s). Five inner defects of potato tubers were assessed: inhomogeneity, discolourations, glassiness, rusty brown spots, and hollow hearts. Sowing material (irradiated) consisted of seed-potatoes (seeds fraction) in the number of 100 for each combination of the experiment. Statistical description of material (seed-potatoes) used in the experiment, was carried out in regard of its mass (tab. 1). The experiment plan included also a control sample. A microwaves generating device of 2.45 GHz frequency with 100 W power was used for irradiation of seed-potatoes. Operation parameters of microwave generator (frequency and operation power and radiation time) were accepted according to the methodology presented in the author's studies [Jakubowski 2009, 2010]. A single seed-potato was placed in a tight chamber equipped with a rotating bottom and a precise time switch-off. Irradiated seed-potatoes and control samples were subjected to initial sprouting germination for 30 days in wooden cases in the temperature of 15-18°C in a laboratory room with the access of natural light. The seed-potatoes, which underwent initial sprouting germination, were placed in soil in the second decade of April. Vegetation of plants took place in the conditions of a cultivated field and experimental fields were arranged in the completely randomnised system. The experiment was located on a light soil, lightly clay sand, IIIa evaluation class (determined according to agricultural usefulness of soils as good, mountainous soil). Care, protection and fertilization of experimental fields was based on guidelines included in Metodyka integrowanej produkcji ziemniaków [2005] and the plants only used rain water resources. The cropping took place after 95 days of vegetation in 2008, after 93 days in 2009 and after 101 days in 2010. Directly after cropping, according to the guidelines *Metodyki obserwacji, pomiarów i pobierania prób w agrotechnicznych doświadczeniach z ziemniakami* IHiAR [Institute for Cultivation and Acclimatisation of Plants] [Roztropowicz 1999], inner defects of potato tubers were marked. 90 potato tubers were collected from each experiment combination (3 repeats with 30 tubers each) of a diameter more than 40 mm.

Potato tubers' defects were determined at a vertical and horizontal cross section of a tuber. Defective tubers included each tuber, in which the following were reported in parenchyma: inhomogeneity, discolourations, glassiness, rusty brown spots or brown centres and hollow hearts. In a 3-level scale (tab. 2) intensification of rusty brown spots and hollow hearts were assessed. In case of determining inhomogeneity, discolourations or glassiness in parenchyma, potato tuber was qualified as a defective (without further assessment and gradation). The results were subjected to statistical analysis on the level of significance α=0.05 with the use of *STATISTICA 9.0*. For the plant vegetation period (May-July) Sielianinow hydrothermal coefficient (S) (arbitrary index of moisture balance) was calculated (on the basis of source materials of IMiGW) as a ratio (1) of monthly precipitation sum (P) and the sum of average daily air temperatures (T) from a given month ($T>0°C$) [Molga 1986]. This index may be useful for determination of the influence of pluviothermal conditions on the examined dependent variables (potato tubers parenchyma defects). Pluviothermal classification of the research periods (months and years) were carried out according to Skowera et al. [2004].

$$S = \frac{\sum P\,[\mathrm{mm}]}{\sum 0{,}1T[°\mathrm{C}]} \quad \text{gdzie } T > 0°C \tag{1}$$

Table 1. The potato tubers' mass used in the experiment (basic statistics)
Tabela 1. Masa sadzeniaków ziemniaka wykorzystanych w doświadczeniu (statystyki podstawowe)

Year	Radiation time	Cultivar	Seed-potato mass [g]			Standard deviation [g]	Coefficient of variation [%]
			minimum	maximum	average		
2008	control sample	Felka B.	54.3	94.3	70.7	7.0	9.9
		Rosara	54.8	95.8	71.7	6.5	9.1
		Velox	54.8	94.8	71.2	9.5	13.3
		Lord	55.2	97.2	72.6	7.7	10.6
	10 s	Felka B.	52.4	91.4	68.5	6.4	9.3
		Rosara	51.9	91.9	68.5	5.3	7.7
		Velox	52.4	93.4	69.4	5.6	8.1
		Lord	52.4	94.4	69.9	7.0	10.0
	20 s	Felka B.	56.2	100.2	74.5	7.3	9.8
		Rosara	57.6	101.6	75.8	7.3	9.6
		Velox	51.9	91.9	68.5	6.6	9.6
		Lord	57.1	99.1	74.4	6.8	9.1
2009	control sample	Felka B.	59.0	104.0	77.7	7.1	9.2
		Rosara	56.2	100.2	74.5	6.6	8.9
		Velox	55.2	96.2	72.1	9.7	13.4
		Lord	53.8	94.8	70.8	7.9	11.1
	10 s	Felka B.	56.2	95.2	72.1	6.5	9.1
		Rosara	58.6	100.6	75.8	5.4	7.1
		Velox	67.1	112.1	85.4	5.7	6.7
		Lord	61.0	105.0	79.0	7.1	9.0
	20 s	Felka B.	56.2	99.2	74.0	7.4	10.1
		Rosara	55.7	98.7	73.5	7.4	10.1
		Velox	54.3	95.3	71.2	6.7	9.5
		Lord	54.3	96.3	71.7	6.9	9.7
2010	control sample	Felka B.	60.0	94.3	73.5	7.1	9.5
		Rosara	59.0	95.8	78.0	6.5	8.3
		Velox	52.0	94.8	69.9	9.5	13.6
		Lord	55.0	97.2	71.0	7.7	10.8
	10 s	Felka B.	56.0	91.4	70.2	6.4	9.1
		Rosara	58.0	91.9	71.4	5.3	7.4
		Velox	49.0	93.4	67.8	5.6	8.3
		Lord	50.0	94.4	68.8	7.2	10.2
	20 s	Felka B.	56.2	100.2	74.5	7.3	9.8
		Rosara	57.6	101.6	75.8	7.3	9.6
		Velox	51.9	91.9	68.5	6.6	9.6
		Lord	57.1	99.1	74.4	6.8	9.1

Source: author's own study

Table 2. The accepted criteria of potato tubers inner defects
Tabela 2. Przyjęte kryteria oceny wad wewnętrznych bulw ziemniaka

Parenchyma defects	Intensification defects	Assessment defects	Assessment criterion
rusty brown spots	considerable	1	numerous lumpy, rusty brown discolourations which take over 20% of the area of the tuber cross-section
	average	2	single, bigger spots or numerous but fine which take 15-20% of the area of the tuber cross-section
	small	3	not numerous fine discolourations which take up to 5% of the area of the tuber cross-section
hollow hearts	considerable	1	tunnels or apertures, which take over 20% of the area of the tuber cross-section
	average	2	tunnels or apertures, which 15 -20% of the area of the tuber cross-section
	small	3	tunnels or apertures, which take over 5% of the area of the tuber cross-section

Source: Roztropowicz 1999

Research results and discussion

Normality of results distribution in samples was examined with *W* Shapiro-Wilk's tests. This test may be used for small samples whereas it is low sensitive to autocorrelation and heteroscedasticity. The value of statistics *W* proved to be significant. Therefore hypothesis on goodness of fit in samples with normal fit should have been rejected. The value of statistics χ^2 was calculated for the researched dependencies, using the median test (tab. 3). Rank sum test of Kruskal-Wallis was applied as a non-parametric counterpart of the analysis of variance for many samples with single classification. For statistically significant dependencies post-hoc tests were carried out which are multiply comparisons of average ranks for the researched samples.

No inhomogeneity, discolouration or parenchyma glassiness of potato tuber parenchyma was reported. The influence of the radiation time on rusty brown spots and hollow hearts of potato tubers of the researched cultivars was not reported. The cultivars did not differ significantly in regard of the hollow hearts occurrence.

Table 3. Influence of the researched independent variables on the occurrence of inner defects of a potato tuber
Tabela 3. Wpływ badanych zmiennych niezależnych na występowanie wad wewnętrznych bulw ziemniaka

Dependent variable and a quality predictor	Value of statistics χ^2	
	Rusty brown spots of parenchyma	Hollow hearts
Year	13.2 (p = 0.000)	6.1 (p = 0.049)
Cultivar	40.8 (p = 0.000)	1.0 (p = 0.791)
Irradiation time	1.3 (p = 0.524)	0.9 (p = 0.642)

Source: author's own study

Table 4. Value of the test probability for multiply comparisons; influence of the year, when the research was carried out on the occurrence of rusty brown spots of potato tuber parenchyma
Tabela 4. Wartość prawdopodobieństwa testowego dla porównań wielokrotnych; wpływ roku, w którym prowadzono badania, na występowanie rdzawej plamistości miąższu bulw ziemniaka

Year	Year and rank value (R)		
	2008 R=1648.2	2009 R=1610.3	2010 R=1603.0
2008		1.000	0.787
2009	1.000		1.000
2010	0.787	1.000	
significant value of Kruskal-Wallis test: H =13.32			

Source: author's own study

Table 5. Value of the test probability for multiply comparisons; influence of the potato cultivar, which was accepted for the research on the occurrence of rusty brown spots of potato tuber parenchyma
Tabela 5. Wartość prawdopodobieństwa testowego dla porównań wielokrotnych; wpływ przyjętej do badań odmiany ziemniaka na występowanie rdzawej plamistości miąższu bulw

Cultivar	Cultivar and rank value			
	Felka Bona R=1617.8	Rosara R=1677.3	Velox R=1599.5	Lord R=1587.4
Felka Bona		1.000	1.000	1.000
Rosara	1.000		0.563	0.319
Velox	1.000	0.563		1.000
Lord	1.000	0.319	1.000	
significant value of Kruskal-Wallis test: H =40.63				

Source: author's own study

Significant (α=0.001) value of statistics χ^2 (13.2) and Kruskal-Wallis test (H=13.3), which were obtained, prove that intensification of occurrence of rusty brown spots of potato tubers parenchyma may differ in particular years of research. Calculated values of the test probability ($p>\alpha$) for multiply comparisons (tab.4) do not prove) however, that this dependent variable differed significantly in the years of experiment. A similar situation occurs in case of differences between potato cultivars in regard of intensification of rusty brown spots (value χ^2=40.8 and H=40.6). Both in the first and the second case abovementioned, a discreet character of the dependent variable distribution and the mechanism of the tests accepted in the statistical analysis may be the reason. Median test and Kruskal-Wallis test or n of independent samples come from the same population or from the population with the same median. Additionally, Kruskal-Wallis test examines deviations from average sample ranks from average value of all ranks and the applied procedure of multiply comparisons of average ranks compares the pairs. Therefore, Kruskal-Wallis test proves diversity between samples and multiply comparisons do not prove it. Moreover, it must be emphasised that the modal value (m) in all researched combinations was m=0. Therefore, data included in tables 4 and 5 allow only for some assessment on the basis of the obtained rank values (R).

The highest intensification of rusty brown spots of parenchyma (tab. 4) was reported in potato tubers examined in 2008 (rank value *R*=1648.2). This year differed from 2010, where intensity of this defect was the lowest (rank value *R*=1603.0). The highest intensification of rusty brown spots of parenchyma (tab. 5) was reported in potato tubers of Rosara cultivar (rank value *R*=1677.3), and the smallest potato tubers of Lord and Velox cultivar (rank values respectively 1587.4 and 1599.5). A period, when the experiment was carried out, may be determined in regard of methoerological conditions as quite humid [Skowera et al. 2004]. 2008 was the year of the highest diversification of pluviothermal conditions. According to S value, May and July were classified as quite humid and June as optimal.

In Lutomirska's [2000] and Ratuszniak's [1994] opinion abiotic factors (such as soil and climate) may influence formation of inner defects in potato tubers. Those authors [Lutomirska 2000; Ratuszniak 1994] emphasise that rusty spots of parenchyma more frequently occur in potato tubers, which come from cultivations on very light impermeable soils. Alternating excess or a long-term lack of precipitation and sudden cooler weather favour the occurrence of this defect (such conditions cause disorders in gas exchange, water management and plant nutrition). The research concerning assessment of inner changes of potato tubers of Baszta and Irga cultivar as a result of variable fertilization and cultivation on two different soils were carried out by Krzysztofik [2003]. Results of these experiments allowed for determination that big tubers (fraction over 50 mm) included more rusty brown spots of parenchyma defects. The author also proved that occurrence and intensification of potato tuber defects of rusty brown spots type and hollow hearts are cultivar dependent features. Brown hollow hearts manifest itself with higher intensification among tubers which come from plants growing on moist soils and rich in nitrogen compounds. The reasons for this defect in parenchyma are disorders of metabolism related to ensymatic amylolysis in a potato tuber. The reason why no diversification in occurrence of hollow hearts between potato cultivars was found in the researched tubers may be the fact that very early cultivars of low and similar content of starch (12-13%) were included in the experiment. Although, the influence of the year (tab. 3), when the research was carried out, occurred to be statistically significant for the intensification of hollow hearts ($\chi^2 = 6.1$), the applied test for multiple comparisons of average ranks in the researched samples did not prove differences between particular years (value of the statistics of Kruskal- Wallis H=6.0 p=0.049). Probably, the interpretation of such a result will be the value of test probability (both for statistics χ^2, as well as for Kruskal-Wallis) p=0.049, which is close to the limit value $\alpha = 0.05$.

Table 6. Values of Sielianinow coefficient in the course of experiment
Tabela 6. Wartości współczynnika Sielianinowa w czasie trwania doświadczenia

Vegetation month	Year of research and values of Sielianinow coefficient			Average
	2008	2009	2010	
V	1.7	1.9	2.2	1.9
VI	1.4	2.1	2.3	1.9
VII	2.1	1.7	2.1	2.0
Average	1.7	1.9	2.2	1.9

Source: author's own study

Conclusions

1. It was not reported that in the accepted times of irradiation, microwaves of 2.45 GHz frequency significantly influenced the intensity of occurrence of the researched potato tuber parenchyma defects in cultivars which were accepted for the experiment.
2. Intensity of occurrence of rusty brown spots and brown hollow hearts differed significantly in the researched years.
3. Intensity of occurrence of rusty brown spots significantly depended on the potato cultivar.
4. No defects such as inhomogeneity, discolourations or glassiness of parenchyma were reported.

Bibliography

Beukema H. P. Van der Zaag. (1990): Introduction to Potato Production. PUDOC. Wageningen, ISBN 90-220 0963-7.

Cabezas-Serrano A., Amodio M., Cornacchia R., Rinaldi R., Colelli G. (2009): Suitability of five different potato cultivars (*Solanum tuberosum* L.) to be processed as fresh-cut products. Postharvest Biology and Technology, 53(3), 138-144.

Haynes K. G. (1998): National Potato Germplasm Evaluation and Enhancement Report. USDA Agricultural Research Service, Beltsville, ISBN/ISSN 8756-2626.

Głuska A. (2002): Wpływ warunków glebowych i rozkładu opadów na plon i niektóre cechy jakości bulw jako ograniczenie w produkcji ekologicznej ziemniaka. Zesz. Prob. Post. Nauk Rol., 489, 113-121.

Jakubowski T. (2010): The impact of microwave radiation at different frequencies on weight of seed potato germs and crop of potato tubers. Agricultural Engineering, 6(124), 57-64.

Jakubowski T. (2009): Reakcja roślin ziemniaka napromieniowanych mikrofalami na symulowany stres suszy. Inżynieria Rolnicza, 8(117), 15-22.

Krzysztofik B. (2003): Zmiany właściwości wewnętrznych bulw ziemniaka wynikające z czynników agrotechnicznych. Inżynieria Rolnicza, 9(51), 119-126.

Leszczyński W. (1994): Wpływ czynników działających w okresie wegetacji ziemniaka na jego jakość. Post. N. Rol., 6, 55-68.

Lutomirska B. (2000): Jak ograniczać wady miąższu bulw ziemniaka. Poradnik Gospodarski, 7-8, 12-13.

Laerke P., Christiansen J., Veierskov B. (2002): Colour of blackspot bruises in potato tubers during growth and storage compared to their discolouration potential. Postharvest Biology and Technology, 26(1), 99-111.

Marks N., Lipiec J., Jakubowski T. (2005): Ocena przydatności metod fizycznych do zwalczania przechowalniczych chorób bulw ziemniaka. Inżynieria Rolnicza, 7(67),169-175.

Mizrach A. (2008): Ultrasonic technology for quality evaluation of fresh fruit and vegetables in pre- and postharvest processes. Postharvest Biology and Technology, 48(3), 315-330.

Molga M. (1986). Podstawy klimatologii rolniczej. PWRL, Warszawa, ISBN 83-09-00200-9.

Nowacki W. (2007): Marketable yield and storage losses of table potatoes grown using organic and integrated farming systems. Journal of Research and Applications in Agricultural Engineering, 52(4), 5-9.

Nowacki W. (2006): Straty plonu handlowego ziemniaków powodowane przez choroby i szkodniki w 2005 roku. Progress in Plant Protection, 46(1), 193-201.

Ratuszniak E. (1994): Wewnętrzne wady bulw ziemniaka. Ziemniak Polski. Instytut Ziemniaka, Bonin, 1, 23-26.
Roztropowicz S. (1999): Metodyka obserwacji, pomiarów i pobierania prób w agrotechnicznych doświadczeniach z ziemniakiem. Instytut Hodowli i Aklimatyzacji Roślin Oddział Jadwisin, ISBN 83-87109-26-6.
Sadowski C., Pańka D., Lenc L. (2004): Porównanie zdrowotności bulw i kiełków wybranych odmian ziemniaka uprawianych w systemie ekologicznym. Zesz. Prob. Post. Nauk Rol., 500, 373-382.
Skowera B., Puła J. (2004): Skrajne warunki pluwiotermiczne w okresie wiosennym na obszarze Polski w latach 1971-2000, Acta Agrophysica, 3(1), 171-177.
Smith I. M., Dunez J., Lelliott R. A., Phillips D. H., Archer S. A. (1988): European handbook of plant diseases. Blackwell Scientific Publications, ISBN 06-32012-22-6.
Metodyka integrowanej produkcji ziemniaków (on-line) (2005): Warszawa. 8-38. [dostęp 9-09-2008]. Dostępny w Internecie: http://www.piorin.gov.pl

OCENA WAD MIĄŻSZU BULW ZIEMNIAKA POCHODZĄCYCH Z SADZENIAKÓW NAPROMIENIOWANYCH MIKROFALAMI

Streszczenie. Celem pracy było sprawdzenie wpływu promieniowania mikrofalowego na powstawanie wad miąższu bulw ziemniaka (niejednorodność, przebarwienia, szklistość, rdzawa plamistość i brunatna pustowatość). W badaniach prowadzonych w latach 2008-2010 uwzględniono bardzo wczesne odmiany ziemniaka: Felka Bona, Rosara, Velox i Lord. W doświadczeniu wykorzystano urządzenie działające z mocą 100 W, generujące promieniowanie mikrofalowe o częstotliwości 2,45 GHz. Wyniki badań, w przyjętych w doświadczeniu czasach napromieniania, nie wskazują na istotny wpływ mikrofal na powstawanie wyżej wymienionych, wewnętrznych wad bulw ziemniaka.

Słowa kluczowe: ziemniak, bulwa, wady miąższu, mikrofale

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