The use of microwave radiation with a frequency of 2.45 GHz as a factor reducing the storage losses of potato tubers

T Jakubowski¹, S Syrotyuk² and K Yankovska²
¹University of Agriculture in Cracow, ul. Balicka 116B, 30-149 Kraków, Poland
²Lviv National Agrarian University, Volodymyra Velykoho St, 1, Dubliany, 30831 Ukraine

Abstract. The goal of the paper is to evaluate the suitability of the 2.45 GHz microwave radiation in reducing the potato tubers storage losses. The experiment was conducted for three consecutive storage seasons on six edible potato varieties. It was determined that reaction of potato tubers to microwave radiation defined by processes taking place during the storage has a varietal character. Some microwave-irradiated combinations showed tendencies for increased germination. One potato variety responded to microwave radiation with significantly lower degree of infection by black scurf.

1. Introduction
Storage of potato tubers ensures their availability when the plants do not produce tubers. At the same time, correct storage of potato tubers significantly reduces the storage losses. Crop protections (mainly chemical) can be used during storage, protecting against agrophages and affecting the life processes of the tuber [1-3]. Application of some physical methods on biological objects can be an alternative to chemicalization of agriculture [4-7]. Many studies have proved that physical action on plants complements the agricultural practices used [8-16]. The impact of physical methods on potato plants (Solanum tuberosum L.) was examined by Jakubowski [17] in terms of action of microwaves of varying frequency. The goal of the paper is to evaluate the suitability of microwave radiation in reducing the potato tubers storage losses.

2. Materials and Methods

The experiment was conducted between 2015 and 2018 for three consecutive storage seasons (Table 1). The assumption was that the microwaves will significantly influence the storage losses of potato tubers in all years of the experiment.

| Table 1. Experiment layout and symbols |
|----------------------------------------|
| Storage season | Potato variety | Combination of experiment | Combination symbol |
| 2015-2018 | Lord, Ovacja, Vineta, Ditta, Finezja, Tajfun | Control | L-k, O-k, V-k, D-k, F-k, T-k |
| 2015-2018 | | tubers irradiation with microwaves | L-m, O-m, V-m, D-m, F-m, T-m |
| 2017-2018 | | tubers irradiation with microwaves + sprout inhibitor | L-m+i, O-m+i, V-m+i, D-m+i, F-m+i, T-m+i |
The experiment was conducted on potato tubers \((Solanum tuberosum\) L.) from six edible varieties of varying earliness and different use (Lord, Owacja, Vineta, Ditta, Finezja and Tajfun). The subject of the experiment was the amount of total potato tubers storage losses. The natural and waste losses were examined. Storage durability indices were determined: total losses, mass loss caused by tuber respiration and transpiration, losses due to germination, and waste losses caused by storage diseases (waste tubers with rot symptoms). In addition, the number of actively germinating eyes was determined along with the degree of tuber periderm infestation by \(Rhizoctonia solani\) Kühn and \(Streptomyces scabies\). The potato yield was calibrated directly after harvesting (according to their width defined as the greater dimension of the largest cross section). The diameter 50-60 mm tubers were selected for storage and were previously marked with their mass and degree of infestation by black scurf \((Rhizoctonia solani)\) and scab. The tubers were microwave irradiated before storage and the power induced in the tubers (absorbed energy) was calculated according to formula described in the author's work [18]. Each combination of the experiment included three replications. The minimum sample size for each replication was calculated on the basis of pilot experiments [19] with the known mean value and standard deviation in the population. The storage experiments were conducted in cold store with automatic temperature control. The tubers were stored at 5-6°C and 90-95% humidity in wooden boxes in order to ensure uniform exchange conditions of heat and tuber mass with the environment. The thermal-hygrometric conditions conformed to the potato tubers storage methodology and were the same in each year of the experiment. The storage period was 181 days (179 days in the 2015/2016 storage season). Directly after the storage period, the mass of tubers, degree of infestation by black scurf \((Rhizoctonia solani)\) and scab, and the mass and number of germs were determined in accordance with the methodology of the Plant Breeding and Acclimatization Institute. The number of germs and the degree of infestation of tuber periderm were determined organoleptically. The evaluation of infestation by pathogens (rhizoctonia R and scab S) was performed before (R0 v S0) and after (R1 v S1) storage on the nine-point scale \((1^\circ - \text{infestation exceeding }25\% \text{ of area, } 9^\circ - \text{no infestation})\). The statistical analysis was performed on the pathogen infestation degree which is the difference between the value \((R \text{ v } S)\) after and before storage \((R1 \text{ v } R0 \text{ v } S1 \text{ v } S0)\). The next step was to determine, for each combination, the percentage indices of: total loss, natural loss, germination loss and disease loss. The mass loss caused by life processes (respiration and transpiration) was calculated for each tuber. The tubers were irradiated using the 2.45 GHz microwave generator. A single tuber was microwave irradiated for 10 s at the constant generator power of 100 W. The generator operating parameters were chosen on the basis of the author’s own research [19] which indicates that irradiation of a seed potato for 10 s with the 2.45 GHz microwaves at the 100 W power accelerates the growth and development of potato plants. A preliminary analysis of results from 2015-2017 (first two storage seasons) showed, in relation to the control group, significantly higher germination losses in the microwave-irradiated combinations. Such result was the reason for a partial modification (expansion) of the experiment. In the last year (storage season 2015/2016) the experiment was expanded to include additional combinations which took into account the effects of growth regulator on the potato tuber germination process. After bipartition, the experiment arrangement included combinations representing the potato variety which tubers were microwave irradiated and exposed to the action of germination inhibitor [20]. The statistical analysis was performed using the STATISTICA 13 package with the assumed significance level of \(\alpha=0.05\).

3. Results and Discussion

The tuber mass variation index (quotient of standard deviation and arithmetic mean) was in the 10.9-26.4% range. The microwave power absorbed by the tubers during irradiation was in the 1.1-1.21 [W] range. The calculated values which define the storage durability of potato tubers, in individual combinations of the experiment, are shown in Table 2.
Table 2. Values of storage evaluation indices, values for the control group are given in parentheses, combination with germination index is marked with (*).

| Years of research | Variety | Indices of storage evaluation (%) | |
|-------------------|---------|-----------------------------------|---|
|                   |         | $L_t$ | $L_n$ | $L_k$ | $L_i$ |
| 2015-2018         |         |       |       |       |       |
| Lord              | 17,4 (17,0) | 8,4 (8,2) | 2,1 (1,7) | 6,9 (7,1) |
| Owacja            | 16,8 (16,5) | 7,8 (7,4) | 1,8 (1,7) | 7,2 (7,4) |
| Vineta            | 17,1 (16,7) | 8,1 (7,8) | 1,9 (1,7) | 7,1 (7,2) |
| Ditta             | 16,6 (16,3) | 7,9 (7,7) | 1,7 (1,6) | 7,0 (7,0) |
| Finezja           | 17,0 (16,7) | 7,9 (7,8) | 1,9 (1,8) | 7,2 (7,1) |
| Tajfun            | 16,5 (16,5) | 8,0 (7,9) | 1,6 (1,6) | 6,9 (7,0) |
| 2017-2018         |         |       |       |       |       |
| Lord*             | 16,3 (16,2) | 7,5 (7,3) | 1,3 (1,5) | 7,5 (7,4) |
| Owacja*           | 16,2 (16,2) | 7,5 (7,4) | 1,4 (1,4) | 7,3 (7,4) |
| Vineta*           | 16,3 (16,4) | 7,4 (7,0) | 1,3 (1,5) | 7,6 (7,9) |
| Ditta*            | 15,9 (16,1) | 7,2 (7,0) | 1,1 (1,4) | 7,6 (7,7) |
| Finezja*          | 16,3 (16,4) | 7,5 (7,5) | 1,3 (1,3) | 7,5 (7,6) |
| Tajfun*           | 16,0 (16,2) | 7,0 (6,9) | 1,1 (1,4) | 7,9 (7,9) |

The calculated storage evaluation values (Table 2, years 2015-2018) indicate some regularity. The total loss index ($L_t$) for microwave-irradiated potato tubers is higher than for the control group tubers. The value of this index is determined by the values of natural loss ($L_n$) and germination loss ($L_k$) indices. However, the statement that it is the germination process which has a decisive impact on the total loss index ($L_t$) is justified because in the part of the experiment with the inhibitor (Table 2, storage season 2017-2018) the differences between the indices ($L_t$) calculated for the irradiated group and the control group are smaller. Worthy of note is the result obtained for the disease loss index ($L_i$). The microwave-irradiated potato varieties (Lord, Owacja, Vineta and Tajfun) had the loss index 1-2% lower than the control group (in the part of the experiment with germination inhibitor, the Vineta variety had the loss index 3% lower than the control group). The results of Shapiro-Wilk and Levene test (conformity of empirical distribution to the normal distribution and the variance homogeneity) sanctioned the application of multi-factor analysis of variance. The analysis of variance indicated significance (F-Snedecor test) of the grouping variables used in the experiment: variety $F=14.06$ and $p=0.000$, and irradiation $F=7.22$ and $p=0.001$. The post-hoc tests were performed for statistically significant quality predictors. The test for samples of different sizes (Spjotvoll and Stoline’s test) was used to determine the homogenous groups. The different number of tubers in combinations was a result of waste losses.

Table 3. Impact of microwave radiation on infestation of tubers by rhizoctonia (result of the Spjotvoll and Stoline’s test), the degree of infestation by rhizoctonia ($R = R_1 - R_0$) is given in parentheses.

| Homogenous groups | 1 | 2 | 3 |
|-------------------|---|---|---|
| O-m (4,33)        | V-m (4,31) |
| T-m (4,28)        | D-m (4,27) |
| F-m (4,19)        | L-k (4,17) |
| L-m (6,30)        | O-k (4,15) |
| V-k (3,91)        | T-k (3,91) |
| D-k (3,90)        | F-k (3,90) |
Table 4. Impact of microwave radiation on the germination process of stored potato tubers (result of the Spjotvoll and Stoline’s test), the number and mass of germs are given in parentheses

| Homogeneous groups | Number of germs (pcs.) | Mass of germs (g) |
|--------------------|-----------------------|------------------|
|                    | 1                     | 2                |
| O-m (3,6)          | D-m (3,4)             | L-m (0,66)       | L-k (0,48) |
| L-m (3,5)          | T-m (3,4)             | V-m (0,61)       | D-m (0,48) |
| V-m (3,5)          | L-k (3,3)             | F-m (0,59)       | O-k (0,46) |
| F-m (3,5)          | O-k (3,3)             | O-m (0,58)       | T-m (0,45) |
| V-k (3,3)          |                       | V-k (0,44)       |             |
| T-k (3,3)          | F-k (0,44)            |                 |             |
| D-k (3,3)          | T-k (0,43)            |                 |             |
| F-k (3,3)          |                       | D-k (0,41)       |             |

Table 5. Impact of the germination inhibitor on the number and mass of germs grown from the microwave-irradiated potato tubers (result of the Spjotvoll and Stoline’s test), the number and mass of germs are given in parentheses

| Homogeneous groups | Number of germs (pcs.) | Mass of germs (g) |
|--------------------|-----------------------|------------------|
|                    | 1                     | 2                |
| O-m (2,4)          |                       | T-k (0,28)       | D-m (0,19) |
| V-m (2,4)          | D-k (0,28)            |                 |             |
| L-m (2,4)          | O-k (0,27)            |                 |             |
| F-m (2,3)          | F-m (0,27)            |                 |             |
| D-m (2,3)          | L-k (0,27)            |                 |             |
| T-m (2,3)          | V-k (0,26)            |                 |             |
| L-k (2,3)          | L-m (0,26)            |                 |             |
| V-k (2,3)          | V-m (0,25)            |                 |             |
| T-k (2,2)          | F-k (0,24)            |                 |             |
| O-k (2,2)          | O-m (0,24)            |                 |             |
| D-k (2,2)          |                       |                 |             |
| F-k (0,22)         |                       |                 |             |

The loss of tuber mass after the storage period was noticed in all combinations of the experiment (an expected effect, a result of life functions: respiration and transpiration). The degree of pathogen infestation was higher than before the tubers were put into the cold store. No significant differences between combinations after storage were noticed for the mass loss and degree of infestation by common scab (P1-P0). Lower degree of infestation by rhizoctonia (R1-R0) after storage was noted in all microwave-irradiated combinations in comparison with the control group (Table 3). However, this difference was statistically significant only in case of the Lord variety (the so-called homogenous groups overlap phenomenon was not taken into account). The microwave-irradiated combinations showed higher activity during the germination process (Table 4). This activity manifested itself in both the number of germinating eyes and in the mass of germs. The mass and number of germs on the tubers of Lord, Owacja, Vineta and Finezja varieties were significantly greater than in non-irradiated combinations. The application of germination inhibitor in the last storage season brought a positive effect (a significantly lower mass of germs) only in case of Ditta and Tajfun varieties (Table 5). The germination in remaining varieties was less intensive, but the differences in the mass and number of germs between the irradiated combinations with and without the inhibitor were not statistically significant. In the author’s opinion, the experiment result does not allow to include the presented physical method based on action of microwaves (frequency 2.45 GHz, power 100 W, and exposure time 10 s) as an independent treatment which guarantees an improved storage durability of potatoes. However, it was shown that microwaves can modify the germination process in tubers of early and very early potato varieties. This information can be useful when choosing the methods of pre-germination or stimulation of seed potatoes. The more intense germination process observed in microwave-irradiated combinations is probably a result of absorption by a potato tuber of the electromagnetic wave energy (biochemical effect of microwave radiation absorption depends on the amount of absorbed energy and
the speed of absorption). It would also be justified to check in similar experiments the effectiveness of the “Talent” growth regulator at other doses (amount and frequency of application) or to check the effectiveness of other germination inhibitors. From the point of view of agricultural product quality, a significant result of the experiment is the effect of microwaves on the rhizoctonia sclerotia. The pockmarked potato tuber periderm is one of the factors which reduce the trade value of the crop. The sclerotia of *Rhizoctonia solani* Kühn can also cause a disturbed growth of the descendant plant in successive phases of its development. The effects of electromagnetic fields and microwave radiation on the pathogenic microorganisms has so far been explained as the process of damaging (tearing) of the cellular membrane which according to Marks [21] leads to the cell destruction. In case of fungi such effect of microwaves may not take place because the cellular membrane of these organisms accumulates chitin (C₈H₁₃O₅N)n, an organic compound – a glucose (β-glucose) polysaccharide. Replacement of some oxygen atoms with nitrogen atoms in the chitin structure results in formation of strong hydrogen intermolecular bonds. Presence of hydrogen bonds of that type can significantly hinder the destructive action of microwave radiation. This explanation is supported by the fact that the energy of a quantum of electromagnetic radiation (10⁻⁴-10⁻³ eV) is significantly smaller than the energy of hydrogen bond (10⁻¹-10⁻² eV). This means that the action of the quantum on the biological structures cannot disrupt even the weakest hydrogen bonds, but it can lead (particularly in case of athermal microwaves) to the conformation changes in cells and thus affect the biochemical processes in the cell. The more probable cause of constraining the *Rhizoctonia solani* Kühn infestation by microwaves is the modifying action of the radiation on storage substances (in case these are lipids, not glycogen) present in sclerotia. It should be emphasized that the penetration depth of electromagnetic energy into the tissue is inversely proportional to the water content in the tissue. When the electromagnetic energy passes through media which contain lipids, it will penetrate deeper than in highly-hydrated tissues. If the storage substance in the form of organic compounds accumulated in sclerotia is responsible for individual stages of the fungus growth, then subjecting it to the action of microwaves can affect the speed of fungus proliferation and its rate of sporulation. Such mechanism of microwave action on the sclerotia of *Rhizoctonia solani* Kühn can explain the lesser degree of infestation of irradiated tubers in comparison with the control group. From the results of experiments by Jakubowski et al. [22] on the *Saccharomyces cerevisiae* cultures it can also be inferred that if the microwave radiation has a stress-inducing effect on *Rhizoctonia solani*, then the reasons of reduced susceptibility of potato tubers to black scurf can also be the oxidation damage of the fungal enzymatic substances which causes an early ageing of the fungi and prevents their reproduction.

4. Summary

The Lord variety responded to the microwave radiation with reduced infestation of tubers by *Rhizoctonia solani* Kühn. The Lord, Owacja, Vineta and Finezja varieties responded to the microwave radiation with greater mass and number of germs on the tubers. As an independent treatment, the microwave-based physical method does not guarantee a better storage durability of potatoes.

5. References

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