Response of potato starch granules to microwave radiation

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Abstract. This study aimed to determine the response of potato starch granules to microwave radiation indicated by changes in starch granule size. Laboratory analyses were carried out in 2019 with tubers of an early edible potato cultivar Innovator. The tubers were irradiated for 10-600 s using a 100 W generator producing microwaves having a frequency of 2.45 GHz. Dimensions of starch granules were measured using an OPTICA B-510BF optical microscope and PROVIEW x64 software, 3.7.13483.20181206. The results were analyzed in STATISTICA 13.3. software package at a significance level of α=0.05. The microwaves were shown to significantly modify the maximal diameter and surface area of potato starch granules.

1. Introduction

The use of electromagnetic fields of various structures to stimulate biological material has been investigated by many authors [1]. For instance, pulsed electric field was employed to inactive microorganisms, especially in the case of liquid bio-substances [2]. The physical methods involving plant material exposure to an electric field, a magnetic field, or an electromagnetic wave have been employed as agrotechnical treatments to, i.a., improve sowing material vitality [3,4]. Studies have shown that the irradiation of seed-potatoes with microwaves having the frequency of 2.45 GHz (using a 100 W generator) for 10-20 s modifies their germination and yielding as well as affects processes ongoing in tubers during storage [5,6]. The microwave treatment of potato tubers before storage was also demonstrated to affect starch content of tubers determined after the storage period [7]. Starch is a plant polysaccharide constituted by D-glucose monomers linked with α-glycosidic bonds. The starch molecule biosynthesis results in the formation of two fractions: non-branched amylose and branched amyllopectin [8]. The botanical origin of starch affects various physicochemical parameters determining its functional properties. Also, the amylose-to-amylopectin ratio influences multiple functional traits of starch, thereby affecting its technological utility, especially in the food industry [9]. The basic functional trait of starch is its capability for gelatinization upon high-temperature hydrothermal treatment. The ability to form a colloidal solution (paste) is mainly determined by the rheological properties of starch [10]. Compared to maize, rice, tapioca, or wheat starches, the potato starch gelatinizes at a relatively low temperature (ca. 55°C), while the viscosity of paste it forms is considered as high [9]. The irradiation
of potato tubers (hydrated to ca. 70%) using microwaves with a frequency of 2.45 GHz induces a thermal effect in starch due to the vibration of water dipoles. The treatment of potato tubers using the physical method based on their exposure to an electromagnetic wave with a frequency of 2.45 GHz can cause structural changes in starch granules. These changes may adversely affect the technological quality of stored tubers intended for fried products because the production of high-quality French fries and chips depends on ensuring a low level of reducing sugars. The storage of potato tubers leads to, among other things, tuber mass losses caused by natural losses (germination, transpiration, and respiration). The respiration process involves the oxidation of carbohydrates, including starch and sugars, and also the emission of carbon dioxide, water, and heat energy. Hence, there is a legitimate need to undertake a study on the effect of microwaves on potato starch granules.

Considering the above, the aim of this study was to determine the response of potato starch granules to microwave radiation measured based on changes in starch granule dimensions (maximum diameter and surface area).

2. Materials and methods

The study was conducted in a laboratory scale in 2019. A null hypothesis (H0) was advanced that the microwave radiation has not effect on starch granule size. It was contradicted to an alternative hypothesis (H1) assuming microwave effect on starch granule size. The study was carried out with tubers of a medium-early, edible potato cultivar Innovator (frequently used to produce French fries). The tubers were weighed and then exposed to the microwave radiation for 10, 20, 30, 40, 50, 60, 100, 180, 200, 300, 450 and 600 s. The exposure time was established based on the parameters of working stations operating based on physical methods used in agricultural research [11,4]. Weight of potato tubers was measured using an AS310.R2 analytical scale (d=0.1 mg) with an RS232 interface. Tubers were irradiated using a generator producing microwaves having the frequency of 2.45 GHz (Figure 1).

To irradiate a potato tuber (9) with microwaves, it was placed inside a generator’s chamber (6), working with the power of 100 W and equipped in a precise time controller (1). The main element of the generator was a magnetron (2) made of an anode block (3) with vacuum cavities, the number and shape of which implied the desired characteristics of the microwave lamp. The anode was placed between the poles of a strong magnet (4), which caused the paths of electrons escaping from the incandescent cathode (5) to curve. The electric vibrations induced in the cavities transformed the resulting electron cloud into an electromagnetic standing wave, and the electrons in the cavities donated their energy (in the form of microwaves) to the outside in the cavities’ electric field. The microwaves were transported to the inside of a sealed chamber (acting as a Faraday mesh), equipped with a rotating bottom (7), through a waveguide (8).

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Figure 1. Scheme of a station for the irradiation of potato tubers with microwaves (description of elements was provided in the text)
Immediately after irradiation of tubers, starch granule size was determined based on its surface area (Sa) and the maximal diameter (φm). Measurements were made for 15 randomly selected starch granules, using an OPTICA B-510BF optical microscope. Images obtained were analyzed in a PROVIEW x64 software, 3.7.13483.20181206.

A microscopic specimen was prepared from fresh pulp of each tuber and stained with Lugol’s fluid (Figure 2). Starch granules were observed at x40 magnification [12,13]. The experiment included also a control sample. A physical parameter which linked the irradiation time (ti [s]) with the microwave generator power (Gp [W]) was the exposure dose (De [J]), being the product of ti and Gp. In turn, the unitary dose of microwave radiation (Du) linked the mass of the irradiated object (Mo [g]) with the exposure dose (De) acc. to the following relation Du = De.Mo⁻¹ [J.g⁻¹]. The analyzed dependent variables (the maximal diameter and surface area of starch granules) were referred to the unitary values of microwave radiation doses (Du) obtained in the experiment.

![Figure 2](image1.png)

**Figure 2.** Image of starch granules in microscopic specimens (a – control sample, b – specimen from irradiated potato tuber)

The results obtained were analyzed at a significance level of α=0.05 using STATISTICA 13.3 software package. One-way analysis of variance was preceded with testing the normality of distribution in the samples (Kolmogorow-Smirnow test) and the homogeneity of variance (Levene test). The null hypothesis was verified based on F-Snedecor test. In turn, the λ-Wilks test was performed to obtain more precise data on the effect of the grouping variable on the dependent variables. Differences between statistically significant means were analyzed using the multiple comparison Duncan test. Groups of homogenous variables were established. Graphics present mean values of the analyzed parameters with error bars for these values determined as +/- 95% of confidence interval. The least square method was used to determine regression curves for the analyzed variables. Finally, values of determination coefficient (R²) and Pearson correlation coefficient (R) were calculated.

3. Results

The results of Kolmogorow-Smirnow and Levene tests allowed performing the parametric analysis of variance. Based on the results of the F-Snedecor test (Table 1), the alternative hypothesis was positively validated, which was a premise to conduct a Duncan multiple comparison test and to determine homogenous groups (Table 2 and 3). The values of the unitary doses of microwave radiation (Du) obtained in the experiment ranged from 8.15 to 508.47 [J.g⁻¹]. The value achieved in the Wilks test, i.e. λ=0.6793 (Table 1), indicates that only approximately 32% of the intra-group differences obtained for the maximal diameter and surface area of starch granules can be explained by the impact of potato tuber irradiation with microwaves.
Table 1. Results of one-way analysis of variance – irradiation effect on the maximal diameter and surface area of starch granules

| Grouping Variable | Test value | Degree of freedom | Test probability |
|-------------------|------------|-------------------|-----------------|
| Free word         | 0.0510     | 2                 | 0.0000          |
| Unit dose radiation (Du) | 0.6793     | 24                | 0.0000          |

![Figure 3](image-url)  

**Figure 3.** Correlation between the unitary dose of microwave radiation and the surface area of potato starch granules

Figures 3 and 4 present correlations between the unitary dose of microwave radiation and the size (indicated by $S_a$ and $\phi_m$) of potato starch granules. As, a high correlation (Figure 5) was found between the analyzed dependent variables ($Pearson R = 0.95$). The correlation between the unitary dose of microwave radiation ($Du$) and surface area ($S_a$) of potato granule can be described with the following function $S_a = Du^2 265.9237 - Du 3497.8996 + 17207.3007$. In turn, the correlation between the unitary irradiation dose and the maximum diameter ($\phi_m$) of potato starch granule can be described with the following function $\phi_m = Du^2 1.5033 - Du 20.5615 + 156.1627$. Finally, the correlation between the analyzed variables takes the form of the following function $S_a = \phi_m 169.17 - 8579$. 

Figure 4. Correlation between the unitary dose of microwave radiation and the maximal diameter of potato starch granules

Figure 5. Correlation between the analyzed dependent variables

The results of the Duncan test allowed distinguishing five homogenous groups describing the effect of the unitary dose of microwave radiation on the surface area of potato starch granules (Table 1) and six groups describing the effect of the unitary irradiation dose on the maximal diameter of starch
granules (Table 2). While planning the experiment, it was a priori assumed that potato tuber exposure to the microwaves having the frequency of 2.45 GHz would cause damage to starch granules, followed by their gelatinization, irrespective of exposure time and tuber size. The research results showed, however, that the unitary irradiation dose of 8.15 \text{[J.g\text{-1}]} caused no significant changes in starch granule size compared to the control non-irradiated samples. It was also observed that the unitary doses ranging from 28.21 to 182.56 \text{[J.g\text{-1}]} significantly decreased both the surface area and the maximal diameter of starch granules, compared to the other experimental combinations tested. The exposure of potato tubers to the higher doses of microwave radiation (359.28–478.46 \text{[J.g\text{-1}]} increased the size of starch granules compared to the tubers irradiated at 28.21–182.56 \text{[J.g\text{-1}]} (expected effect evoked by potato tuber temperature increase). The results of the study demonstrate that the microwave radiation with a frequency of 2.45 GHz can act as an abiotic stress factor which in the mentioned range of unitary irradiation doses (28.21–182.56 \text{[J.g\text{-1}]} induces a defense reaction of cells manifested by their shrinkage.

In addition, as indicated by previous studies [14,15,16,17], not all starch granules are involved in the gelatinization process at the same time because granules of various sizes gelatinize at different temperatures. In the course of the gelatinization process, the structural changes are firstly observed for the large granules, whereas smaller granules are more resistant in this respect (therefore, rather the term ‘pasting temperature range’ than the term ‘pasting temperature’ is used in the literature).

Table 2. Results of Duncan test – effect of the unitary dose of microwave radiation on the surface area of potato starch granules and the distribution of homogenous groups

| Unit dose radiation (Du) | Surface area (μm²) | Homogeneous group |
|-------------------------|--------------------|------------------|
|                        |                    | 1  | 2  | 3  | 4  | 5  |
| 53.19                   | 4142.74            | **** |    |    |    |    |
| 66.14                   | 5583.47            | **** | **** |    |    |    |
| 47.32                   | 6122.88            | **** | **** |    |    |    |
| 182.56                  | 6653.19            | **** | **** |    |    |    |
| 37.41                   | 7625.19            | **** | **** | **** |    |    |
| 25.25                   | 8287.32            | **** | **** | **** |    |    |
| 28.21                   | 8287.32            | **** | **** | **** |    |    |
| sie.15                  | 10251.38           | **** | **** | **** |    |    |
| 359.28                  | 10332.68           | **** | **** | **** |    |    |
| 478.46                  | 12274.39           | **** | **** | **** | **** |    |
| 423.39                  | 12274.39           | **** | **** | **** | **** |    |
| 0                       | 14734.64           | **** | **** |    |    |    |
| 508.47                  | 16607.95           | **** |    |    |    |    |

Table 3. Results of Duncan test – effect of the unitary dose of microwave radiation on the maximal diameter of potato starch granules and the distribution of homogenous groups
| Unit dose radiation (Du) | Maximal diameter (μm) | Homogeneous group |
|------------------------|-----------------------|-------------------|
| 53.19 | 73.0457 | **** |
| 47.32 | 85.4633 | **** **** |
| 66.14 | 86.8597 | **** **** |
| 182.56 | 88.9433 | **** **** |
| 37.41 | 95.0587 | **** **** **** |
| 28.21 | 97.7367 | **** **** **** **** |
| 25.25 | 109.948 | **** **** **** **** |
| 359.28 | 113.5377 | **** **** **** **** **** |
| 478.46 | 114.2233 | **** **** **** **** **** |
| 423.39 | 123.836 | **** **** **** **** **** |
| 8.15 | 126.3333 | **** **** **** |
| 0 | 132.897 | **** **** |
| 508.47 | 142.3367 | **** |

4. Conclusion
1. Microwaves modify the maximal diameter and surface area of potato starch granules.
2. Microwaves used in unitary doses ranging from 28.21 to 182.56 [J.g⁻¹] decrease the size of potato starch granules.
3. Microwaves used in unitary doses ranging from 359.28-478.46 [J.g⁻¹] increase the size of potato starch granules.

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