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The effect of storage duration and UV-C stimulation of potato tubers, and soaking of potato strips in water on the density of intermediates of French fries production

***Abstract**. The paper presents data on the effect of storage duration and UV-C stimulation mode of potato tubers and soaking of potato strips in water on strip density. The study was conducted on potato tubers of the Innovator variety cut into strips with a cross-section of 10 x 10 mm and 60 mm long. Strips were cut along the longitudinal tuber axis set between proximal and distal tuber end. The studies were conducted on tubers at two time points: 1. after 3-month storage and 2. after 9-month storage. Potato tubers were stimulated by UV-C using the following modes: 1 and 3 – irradiation on one tuber side for 30 min, 2 and 4 – irradiation on opposite tuber sides for 15 min each, 0 – control group (not irradiated). Tubers irradiated according to mode 1 and 2 were stimulated 2 days before processing whereas according to modes 3 and 4 before storage. Strips were soaked in water (1) at a temperature of 20oC for 15 min and (2) at a temperature of 40°C for 20 min. In addition, the studies included the strips blanched at a temperature of 90°C for 2 min and the control group comprising unsoaked strips. The storage and laboratory experiments were conducted in 2016-2017. Strip density was statistically significantly dependent on storage duration, stimulation and soaking conditions. Prolongation of storage and UV-C stimulation of tubers prior to storage (in both variants) and prior to processing (longer irradiation on one side of the tuber) increased the density of the strips. On the other hand, raising the soaking time from 15 min to 20 min and water temperature from 20°C to 40°C reduced strip density.*

***Streszczenie.** W pracy przedstawiono wpływu terminu przechowywania i napromieniania UV-C bulw oraz zanurzenia słupków ziemniaczanych w wodzie na gęstość półproduktów na frytki. Jako materiał do badań wykorzystano bulwy ziemniaka odmiany Innovator. Badano obiekty w kształcie słupków o przekroju 10x10 mm i długości 60 mm. Słupki wycinano wzdłuż najdłuższej osi bulw, wyznaczonej pomiędzy częścią wierzchołkową i pępkową. Badania wykonano na bulwach w dwóch terminach: 1 - po 3 miesiącach i 2 - po 9 miesiącach przechowywania. W celu naświetlenia bulw ziemniaka stosowano następujące parametry stymulacji UV-C: 1, 3 - naświetlanie 30 min z jednej strony bulwy, 2, 4 - naświetlanie po 15 min z dwóch przeciwnych stron bulwy, 0 - próba kontrolna (bez naświetlania). Stymulację bulw w sposób 1, 2 prowadzono na dwa dni przed przetwarzaniem, a naświetlanie 3, 4 przed przechowywaniem. Proces sorpcji realizowano poprzez zanurzanie badanych obiektów w wodzie o temperaturze: 1 - 20°C w czasie 15min i 2 - 40°C w czasie 20min. Do badań przyjęto ponadto słupki poddane blanszowaniu 3 - 90°C i 2 min oraz próbę kontrolną 0 - bez zanurzania. Doświadczenia przechowalnicze i laboratoryjne realizowano w latach 2016-2017. Na gęstość słupków statystycznie istotny wpływ miały termin przechowywania, stymulacja i warunki zanurzenia półproduktów. Wzrost czasu przechowywania oraz zastosowanie stymulacji UV-C bulw przed przechowywaniem (w obu przyjętych wariantach) i przed przetwarzaniem, w wersji naświetlani dłuższym czasem z jednej strony bulw, skutkowało zwiększeniem gęstości półproduktów. Wzrost czasu zanurzenia półproduktów z15 do 20min i temperatury wody z 20 do 40 °C powodował obniżenie gęstość półproduktów. (**Wpływ czasu przechowywania i stymulacji UV-C bulw ziemniaka oraz namaczania pasków ziemniaka w wodzie na gęstość półproduktów z produkcji frytek**)*

Keywords: UV-C, density, potato strips, French fries.
Słowa kluczowe: UV-C, gęstość, słupki ziemniaczane, frytki.

Introduction

Density is one of the basic parameters determining the efficiency of potato tuber processing technology. This parameter influences the yield of dried and fried potato products. When density increases, the expenditure of energy, necessary for water evaporation during drying and frying of potato products, is reduced. Potato tuber density affects quality parameters of French fries and chips, is decisive for fat absorption during frying and significantly affects their consistency [1, 2]. Tubers stored for long periods transpire through the periderm and at final stages also through sprouts which causes an increase in tuber density [3,4]. Studies by Sobol [4, 5] indicated that peeled soaked potato tubers absorbed water which reduced their density. The magnitude of tuber density reduction due to water absorption depends on storage stage, size fraction, varietal traits and, to a lesser extent, fertilsation method. Experiments conducted by Sobol [5, 6] revealed that 3.5-hour water absorption was necessary to completely compensate for the increase in the density of a medium tuber after 8 months of storage. Changes in the density of tubers soaked in water depend on diffusion time, solvent (water) temperature, size fraction and potato variety [4, 5]. Studies by Sobol [6] also indicated the dynamics of density reduction of intermediates in (French fries and chips production caused by water absorption was many times greater compared with changes occurring in the whole tubers. Experimental results demonstrated that the time needed for balancing water loss, caused by transpiration of tubers during 8-month storage, amounted to 5.0-7.0% for intermediates of French fries production and 2.0-2.5% for chips compared with the time required for the whole tubers [5]. Dynamics of diffusion processes occurring between solvent (water) and tuber tissue (semi-finished product cut from the tuber) largely depends on the area of mass exchange-to-product volume ratio [6].

UV radiation is mostly used in food processing technology as a sterilisation method of food products [7, 8]. Allende [9] investigated the use of this physical factor for the production of *Gluconacetobacter xylinus* mutants, which were then used for glycerol biotransformation into DHA (the best mutant synthesized 18.00 mg DHA cm^{-3}, i.e. by 32% more DHA cm^{-3} than the parent strain). Photodegradation of humic acids by UV-C radiation was investigated by Sławińska [10]. Her experiment demonstrated that absorption and fluorescence spectroscopy could be used for determination of resistance to UV-induced degradation. Szwarc [11] investigated the effect of UV radiation on Augusta soy plants. UV radiation reduced photosynthesis and chlorophyll content and had a negative impact on growth and biomass of the above-ground parts of soy plants while the plant responded with defensive reactions such as increased synthesis of flavonoids and activation of antioxidant enzymes (peoxidase and catalase). UV-C radiation was also used for reduction of natural microflora on lettuce leaves [9], in procedures aimed to improve the quality of onions (*Allium cepa* L.) and tomatoes (*Solanum lycopersicum*) after storage [12, 13] and on asparagus (*Asparagus offificinalis* L.), especially to reduce pathogens [14]. In *Solanum tuberosum*, the effect of UV-C radiation on seed potatoes of the Jelly variety was studied to establish its impact on later ontogenesis of potatoes [15]. In addition,

Lin [16] investigated the reaction of potato plants of the Atlantic variety to UV-C radiation during tuber storage at low temperatures. It was shown that UV-C irradiation of tubers led to a reduction of the contents of reducing sugars (fructose and glucose) after storage. Other authors took also other experiments on the behaviour of plants under the influence of pulsed electric field even the influence of preparation of substrates on which the plants are grown [17,18].

The aim of the present studies was to determine the effect of storage duration and UV-C irradiation of potato tubers and soaking of potato strips in water on the density of intermediates of French fries production.

Material and Methods

Storage and laboratory experiments were conducted in 2016-2017. The studies were conducted on the Innovator potato tubers. The Innovator variety belongs to the most commonly used varieties for French fries production by European, including Polish, companies. It is an early variety of culinary type B with regular round-oblong tubers, shallow eyes and medium content of starch (14.6%). This variety is very resistant to darkening of raw and cooked flesh, and keeps well. The studies of changes in strip density caused by water absorption after soaking involved measurements of weight of study objects in air and in demineralized water. Intermediates for French fries production, namely potato strips measured 10 x 10 mm in cross-section and 60 mm in length. The strips were cut along the longitudinal tuber axis set between proximal and distal tuber end. Strips were soaked in demineralized water at a temperature of: (1) 20^{o}C for 15 min and (2) 40^{o}C for 20 min. In addition, the studies included strips blanched at (3) 90^{o}C for 2 min. and control group (0) where strips were not soaked. In order to obtain equal measurement conditions, prior to measurement, strips were immersed in water and immediately dried (in two stages) using a dry paper towel each time. The same procedure was applied to strips soaked in water, namely two-stage drying was performed directly after measurement [3, 6]. Calculations of density changes caused by water absorption were described in detail in papers by Sobol [3, 6]. Studies were conducted, in triplicate, at two time points: (1) after 3-month storage and (2) after 9-month storage. Tubers were stored at a temperature of 10^{o}C and 90-95 % humidity.

A device for UV-C irradiation of biological material was equipped with a radiator TUV UV-C NBV 15 W (irradiance of 253.7 nm line at a 1 m distance from the lamp was 0.42 W.m^{-2}, total energy flux of 253.7 nm line was 4.0 W). Radiator structure allowed for continuous regulation of the height above the chamber bottom in the range from 0.4 to 1.0 and The method of UV-C irradiation was described in paper by Jakubowski [15]. The following UV-C irradiation modes of potato tubers were used: 1, 3 – irradiation on one tuber side for 30 min, and 2, 4 – irradiation on opposite tuber sides for 15 min on each. The stimulation according to modes 1 and 2 was conducted 2 days prior to strip production and soaking in water whereas stimulation according to modes 3 and 4 was conducted prior to storage. The experiment included also a control sample (0) (not irradiated).

Each combination experiment contained 3 replications. In the experiment, 3600 objects with a total mass of 21600 g were studied. The statistical analysis was performed using the STATISTICA 13.1 package with the assumed significance level of $\alpha = 0.05$. The minimum number of objects necessary to achieve the goal of the research was determined. The minimum sample size was determined using the t-test for a single sample. With the mean values of the population and standard deviation known from pilot experiments, the power of test was assumed at 0.9 and the probability of type I error at $\alpha = 0.05$. The conformity of empirical distribution to the theoretical (normal) distribution was determined using the Shapiro-Wilk test. The variance homogeneity was examined using the Levene test. The impact of statistically significant quality predictors was examined with the post-hoc test using the Duncan procedure.

Results and Discussion

There were no statistically significant differences between the reiteration. Three-way analysis of variance indicated that all experimental variables, i.e. storage duration (1), tuber stimulation (2) and strip soaking conditions (3) statistically significantly influenced density of potato strips which were intermediates for French fries production (Tab. 1). All interactions between factors were also statistically significant.

The effect of tuber storage duration, presented in Fig. 1, on strip density is in agreement with earlier studies [3, 4, 6]. The increase in strip density from 1.069 (g·cm^{-3}) at time point 1, i.e. after 3-month storage to 1.097 (g·cm^{-3}) at time pint 2, i.e. after 9-month storage was caused by: (1) increased transpiration of water from tubers at the final period of storage due to transpiration not only through the skin but also through sprouts, (2) reduced tuber absorption capacity in the final storage period (Sobol 2007a) caused probably by intense aging of tubers and changes in cell membranes. Thus, strips cut out from tubers stored for 9 months showed a higher density than those cut out from tubers stored for 3 months.

Table 1. The effect of storage duration and stimulation of potato tubers and soaking conditions of potato strips in water on strip density (three-way analysis of variance).

Qualitative predictor	F- Snedecor test	p - test probability
Word free	8871722	0.00
{1} Storage term	1427	0.00
{2} Stimulation	41	0.00
{3} Conditions of immersion of the intermediate	33	0.00
1*2	29	0.00
1*3	28	0.00
2*3	13	0.00
1*2*3	11	0.00
Error		

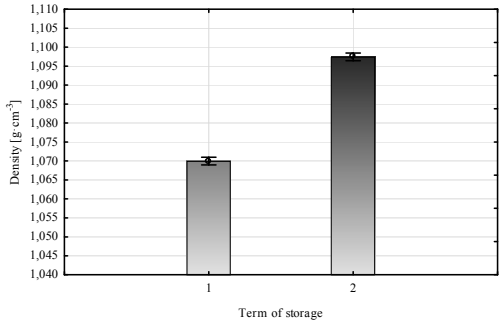

Fig. 1 The effect of tuber storage duration on strip density.

Analysis of data on the effect of UV-C radiation revealed that tuber irradiation significantly affected potato strip density (Tab. 1) (Fig. 2). The Duncan test (Tab. 2) classified the studied strips into three uniform groups: group 1 comprised strips from tubers stimulated according to mode 1(1.087 (g·cm-^{3})), 3 (1.087 (g·cm^{-3})) and 4 (1.088 (g·cm^{-3})); group 2 included strips formed from unstimulated tubers

(1.077 (g·cm^{-3})); and group 3 contained strips from tubers stimulated according to mode 2 (1.079 (g·cm^{-3})). Changes in strip density analyzed in the period from 3 to 9 months of storage depended on the stimulation mode. The lowest density in this part of the experiment (1.077 (g·cm^{-3})) was observed for unstimulated strips. UV-C stimulation of tubers before processing, on one side for 30 min (mode 1) and before storage, on one side for 30 min (mode 3) and on both sides for 15 min on each (mode 4) resulted in the highest density of strips (1.087–1,088 (g·cm^{-3})). This result can indicate that:

1 - intense irradiation of tubers on one side (mode 1) before processing could affect the tissue of strips cut from them in such a way that diffusion was slowed down;

2 - irradiation of tubers before processing (mode 3) could produce a similar effect as in stimulation according to mode 1;

3 - irradiation of tubers before storage (modes 3 and 4) could lead to excessive transpiration during long-term storage.

The experimental results on the changes in strip density (described below) and on the impact of different stimulation modes in various storage periods (Fig. 4) appear to confirm the above suggestions. Moreover, such effects of the used stimulation modes can be corroborated by results of studies on strip density in the control group and stimulation mode 2. No stimulation and irradiation for 2 x 15 min increased dynamics of diffusion processes, thus, strips from unstimulated tubers showed the lowest density while strips from irradiated tubers when the dose was uniformly scattered over the whole area on both sides before processing showed a slightly higher density (Tab. 2, Fig. 2).

Table 2 The Duncan test results - homogeneous groups (*) with respect to the stimulation mode.

Difference in density (g·cm^{-3})				
Stimulation	Average	homogeneous groups		
		1	2	3
0	1.0769		*	
2	1.0793			*
1	1.0869	*		
3	1.0874	*		
4	1.0881	*		

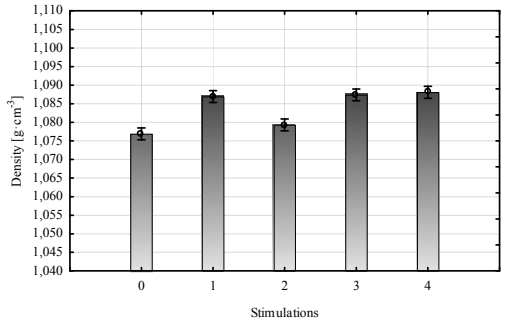

Fig. 2 The effect of tuber stimulation on potato strip density.

Increased absorptive capacity of potato strips can be explained by plant response to irradiation by activation of a defensive mechanism for protection against harmful effect of UV-C radiation. This mechanism acts via flavonoids, mostly flavonoles and anthocyanins, which are able to reduce UV transmission through epidermis (with concomitant transparency to PAR) which protects plant DNA and photosynthetic apparatus. Trichomes can additionally scatter even up to 70% of UV radiation reaching the plant. According to Tevini [19], Robin [20] and Cockeeli et al. [21], apart from flavonoids, also carotenoids are plant dyes protecting the plant against harmful action of UV radiation due to their antioxidant and reactive oxygen species quenching ability. It can be assumed that the same mechanism of electromagnetic wave absorption operates in plants as that described in physiotherapy, namely that radiation in the wavelength range 184.9-290 nm penetrates into human skin to a depth of 2 mm. The studies indicate that UV-C can even deeper penetrate into the tissue of potato tuber. In addition, the Grotthuss-Draper law applies to all irradiated objects (photochemical reaction in the responding system can be induced only if light is absorbed by this system) [22]. UV radiation induces photochemical reactions in biological systems, like photosynthesis, photolysis, photoisomerization, oxidation or reduction. In potato tubers, photoisomerization would involve transformation of flavonoids into another isomer by the action of photons.

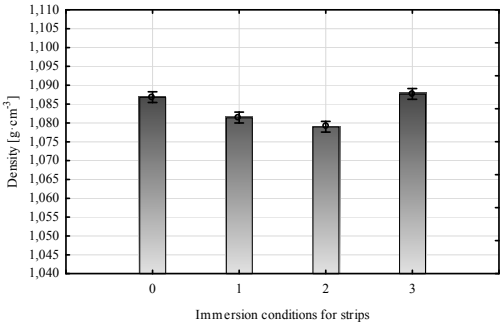

Fig. 3 The effect of strip soaking conditions on their density.

Table 3 Results of the Duncan test - homogeneous groups (*) with respect to strip soaking conditions.

Difference in density (g·cm^{-3})				
Immersion conditions for strips	Average	homogeneous groups		
		1	2	3
2	1.0789		*	
1	1.0814			*
0	1.0868	*		
3	1.0877	*		

Soaking conditions of potato strips in water significantly influenced their density. The lowest density of 1.078979 (g·cm^{-3}) was observed for strips soaked in water at a temperature of 40^{o}C for 20 min. When strips were soaked in water at a temperature of 20^{o}C for 15min, their density amounted to 1.081362 (g·cm^{-3}), whereas after soaking in water at 90^{o}C for 2 min, strip density of 1.087683 (g·cm^{-3}) was achieved. Density of control strips was 1.0868 (g·cm-3). The Duncan test (Tab. 3) classified the studied strips into three groups: group 1 comprised soaking conditions designated as 0 and 3, group 2 soaking conditions 2 and group 3 soaking conditions 1. Such density distribution after soaking of strips under conditions 1 and 2 (water temperature lower than starch gelatinization temperature) is confirmed by earlier studies by Sobol [6], and results from the following relations:

- raising the solvent (water) temperature from 20^{o}C do 40^{o}C induces reduction of its density, thus the effect of diffusion is more pronounced;
- prolongation of diffusion time (between water and strip tissue) leads to density reduction.

The highest density of strips was achieved after their soaking at 90^{o}C for 2min, which resulted from a short diffusion time and formation of a layer of gelatinized starch on the strip surface which probably caused a partial barrier for water absorption. Moreover, due to high difference of

temperatures (between strips and surroundings), a part of water evaporated after strips were taken out of water.

Detailed analysis of the obtained results (Fig. 4) indicates that the highest density was achieved for samples stimulated with UV-C radiation according to 1, 3 and 4 mode. This relation was observed mostly at the time point 2, i.e. after 9-month storage. The obtained strip density distribution in the final storage period, linked with the stimulation mode, generally determines the relations of the results obtained in the whole experiment. Probable explanation of the obtained relationships was presented in the earlier section of the paper dealing with the effect of stimulation mode on strip density.

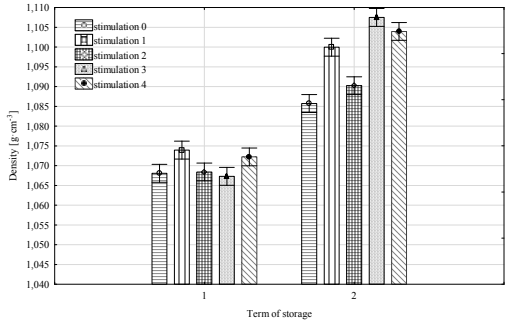

Fig. 4 The effect of tuber storage duration on strip density for specific stimulation modes.

Analysis of the effect of storage duration of potato tubers on strip density for specific soaking conditions (Fig. 5) indicates that for both storage times, the highest density was observed for strips soaked in water at 90oC for 2 min or unsoaked (sample 0). In the first storage period, application of the remaining two soaking conditions (1 and 2), with soaking duration from 15 to 20 min and water temperature from 20 to 40^{o}C demonstrated that strip density decreased with increasing the soaking time and water temperature. In the second storage period, these relations were slightly flattened and the results from the first storage period were decisive for the result of the whole experiment (Fig. 5).

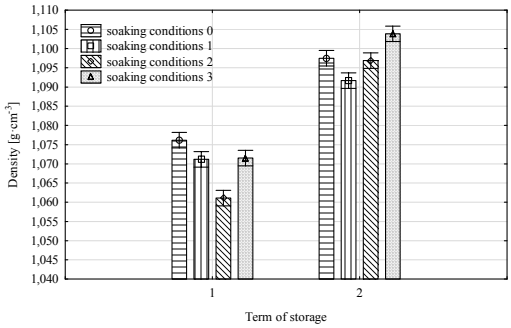

Fig. 5 The effect of tuber storage duration on strip density for specific strip soaking conditions.

Conclusions

1. Strip density statistically significantly depends on storage duration, stimulation and soaking conditions of intermediates of French fries production.
2. Strip density increases with tuber storage time.
3. Tuber stimulation prior to storage in both variants and prior to processing with longer irradiation on one tuber side, increases strip density.
4. Increasing the soaking time and water temperature (up to starch gelatinization temperature) reduces the density.

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