Effect of UV-C Irradiation on the Shelf-Life of Fresh-Cut Potato and Its Sensory Properties after Cooking

Running head: UV-C fresh-cut potato

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SUMMARY

Research background. Potato tissue is injured during fresh-cut production which makes fresh-cut potato (FCP) susceptible to the quality loss and microbiological spoilage. At the same time such products are desirable due to their convenience, however they are extremely sensitive and have short shelf-life. The main challenge of the FCP industry is to find possibilities to overcome these drawbacks where UV-C treatment, known for its antibacterial activity, is a promising technique and it shows a certain potential.

Experimental approach. The influence of the UV-C light treatment on the safety, and quality as well as sensory traits of FCP (Solanum tuberosum L. cv. Birgit) during storage was examined. For this purpose, 0, 3, 5- and 10-min UV-C irradiation was applied on vacuum packaged potato slices pre-treated with sodium ascorbate solution. During 23 days' storage at (6±1) °C, microbiological, physicochemical and sensory properties of raw samples were monitored, and sensory properties of boiled and fried FCP also.
Results and conclusions. The 5- and 10-min UV-C treatment significantly reduced microbial growth, increased total solids and lightness - $L^*$, and positively affected odour and firmness of raw potatoes. Cooked UV-C treated samples were described with more pronounced characteristic potato odour and taste. Overall, UV-C treated FCP retained its good quality and sensory traits up to 15 days at (6±1) °C.

Novelty and scientific contribution. To the best of our knowledge, this is the first scientific article dealing with the effect of UV-C light on durability (safety, quality and sensory traits) of FCP cv. Birgit and its suitability for boiling and frying. In general UV-C treatment is a known antimicrobial technique, but its application for FCP is poorly explored. Results proved that FCP treated with UV-C without addition of chemical preservatives and associated only with the effect of sodium ascorbate (anti-browning agent) and vacuum packaging, can provide two-fold longer shelf-life at (6±1) °C when compared to UV-C untreated FCP. UV-C treated FCP retained good overall quality and sensory properties either raw, boiled or fried. Results of this study could also be useful for producers in terms of potential UV-C application as a strategy for prolongation of FCP shelf-life.

Keywords: fresh-cut; storage; microbiology; sensory; sodium ascorbate; PCA

INTRODUCTION

The popularity and commercial importance of the fresh-cut (FC) products are growing due to extreme convenience in home meals preparation and catering industry as well as in many other food services. The FC fruits and vegetables are processed only by washing, trimming, peeling and/or cutting, and packaged to maintain its freshness and high nutritional value (1). Therefore, they are susceptible to microbial growth, water loss, off-odour, tissue softening, browning and general loss of quality what makes them very perishable and limits its shelf-life (2). During FC processing, due to cell integrity damage, enzymes and their substrates are delocalized, what results with higher enzymatic activity responsible for oxidative reactions. Such reactions lead to formation of brown melanoid pigments (3).

Fresh-cut potato (FCP) presents potentially interesting potato product (4) and many studies have been dealing with finding solutions to preserve quality and safety of FCP as well as to extend its shelf-life. For this purpose, appropriate cultivar, anti-microbial and anti-browning agents, packaging materials and conditions as well as storage conditions have been researched (5,6). According to our latest published study FCP cv. Birgit pre-treated with sodium ascorbate (SA) solution and vacuum-packaged showed promising results during 8 days' storage at 10 °C (5). Besides above-mentioned approaches, non-thermal UV-C
technology has been investigated, especially in terms of prolonging a shelf-life by preventing microbial growth and enzyme activity (7). Antimicrobial effect of UV-C has a maximum effect at 254 nm and its effectiveness is based on structural changes in the microorganism’s DNA caused by cross-linking between pyrimidine, which consequently contributes to the inability of transcription and replication of the cells (8). However, the irradiated plant tissue can be damaged using high UV-C doses (9). Besides, effectiveness of UV-C irradiation on enzyme activity depends on applied dose and on sensitivity of enzymatic proteins, what is highly correlated with their nature (10,11). By exposing the enzyme to irradiation some spatial-structure changes could occur and better exposure of the enzyme active sites is enabled, consequently leading to an initial increase in enzyme activity (12). Thus, for extending shelf-life of FC products it is necessary to evaluate the optimal doses of UV-C irradiation considering the properties of the plant and already mentioned anti-browning agents, packaging materials and packaging conditions as well as storage conditions.

According to Teoh et al. (6) the optimal UV-C dose was 684 mJ/cm² for potato slices dipped in ascorbic acid and calcium chloride solution, closed in permeable plastic boxes at 4 °C and stored for 10 days. Such dose decreased activity of polyphenol oxidase, phenylalanine-lyase and peroxidase. Moreover, a significant decrease in browning and enzyme activity as well as increase in firmness were observed in the study of Xie et al. (13) where potato slices were treated with sodium acid sulphate, irradiated with UV-C for 3 min and stored in polyethylene bags for 25 days at 4 °C.

Selection of the packaging material is also very important, particularly if slices are packaged and then UV-C treated. The permeability of materials to UV-C irradiation depends on the type of the used polymers as well as on its thickness. It was found that 40 µm thick polyamide/polyethylene laminate was permeable for 80 % UV-C irradiation (11).

Furthermore, UV-C treatment showed a positive effect on soft rot prevention in potato seed tubers (14). Also, irradiation of tubers reduced accumulation of fructose and glucose during cold storage, what consequently lowered the formation of toxic acrylamide during frying (15), and increased brightness of the fries (16).

However, although there is a number of studies which have dealt with quality properties of cooked potatoes without UV-C treatment (17,18) or with UV-C pre-treatment of tubers (16, 19,20,21), reports regarding the effect of UV-C light on FCP and its effect on the quality and sensory attributes of raw and cooked FCP are scarce.

Therefore, the aim of this study was to investigate the effect of different UV-C irradiation doses and 23 days’ storage at (6±1) °C on microbial growth, quality and sensory properties of
FCP cv. Birgit, pre-treated with SA solution and vacuum packaged, as well as on sensory properties of FCP after boiling and frying.

MATERIALS AND METHODS

Plant material

Potato (*Solanum tuberosum* L.) tubers of cv. Birgit were harvested in Slavonia region (Croatia) during 2019, treated with anti-sprouting agent (Gro Stop Basis and Gro Stop Fog, Certis Europe B.V., United Kingdom) and stored one month in the dark (8 °C/RH app. 100 %) before analysis.

Sample preparation

Undamaged and uniformed potato tubers were selected, washed, drained, hand-peeled and sliced (0.4 cm) using a commercial slicer (SFS 1001 GR, Sencor, Ricany, Czech Republic). Immediately after slicing, potatoes were dipped in SA solution (2 %, m/V) for 3 min according to the procedure described by Dite Hunjek *et al.* (18). After draining, potato samples (4-6 slices) were vacuum packaged (SmartVac SV 750, Status, Metlika, Slovenia) in one single layer within the polyamide/polyethylene (PA/PE) double-layered (100 and 130 µm) vacuum pouch (Status, Metlika, Slovenia).

UV-C treatment

The UV-C treatment of potato slices was performed in an UV-C chamber (UVpro EKB 100, Orca GmbH, Kürten, Germany) equipped with 4 UV-C lamps (4xHNSL 24W, maximal emission at 253.7 nm, UVpro). The samples were irradiated for 0 (control), 3 (3-UV-C), 5 (5-UV-C) and 10 min (10-UV-C) to obtain doses of 0, 162, 270 and 540 mJ/cm² outside and 0, 108, 180 and 360 mJ/cm² inside of the vacuum bags (UVCpro UVC-LOG radiometer, Orca GmbH, Kürten, Germany). Afterwards, the UV-C untreated and treated samples were stored at (6±1) °C and analysed at the beginning of the storage (0), on the 8th day, whereas in our previous study it was found that 8 days' stability can be achieved using VP and SA treatment (5), and on the 11th, 15th and 23rd day of storage. Experiment was done in duplicates.

Packaging oxygen permeability determination

Oxygen permeance cm³/(m²·day·kPa) determination was performed using manometric method on a permeability testing appliance (GDP-C, Brugger Feinmechanik GmbH, Germany). The increase in pressure during the test period was evaluated and displayed by an external computer. Data were recorded and permeance was calculated automatically. The sample
temperatures (23±1) °C were adjusted using an external Thermostat (HAAKE F3 with Waterbath K, Haake GmbH, Karlsruhe, Germany). All measurements were carried out in duplicates.

**Microbiological analysis**

Determination of total aerobic mesophilic bacteria count (AMBC) was carried out according to the Horizontal method – Colony count technique at 30 °C (22). Dilutions were made with peptone water (0.1 %, m/V) and surface plated (1 mL) in duplicate on plate count agar (Biolife, Milan, Italy). The plates were incubated at (30±1) °C for (72±3) h in dry heat oven (FN-500, Nüve, Ankara, Turkey). Analysis were performed on raw samples and the results were expressed as mean values of log CFU/g.

**Determination of total solids, soluble solids and pH**

The raw potato slices were homogenized (Bosch MSM89160 blender, Robert Bosch GmbH, Gerlingen-Schillerhöhe, Germany) and used for determination of total solids (TS), soluble solids (SS) and acidity. TS were calculated as a percentage of the mass ratio before and after drying potato samples at (105±1) °C (FN-500, Nüve, Ankara, Turkey) to a constant mass, while SS were determined by a digital refractometer (DR201-95, A. Krüss OPTRONIC GmbH, Hamburg, Germany) at 20 °C and expressed as °Brix. The pH was measured by a pH meter (pH 7110, inoLab, WTW 82362, Wellheim, Germany). All measurements were carried out in duplicates and results were expressed as mean value±standard error (SE).

**Firmness analysis**

The firmness of raw FCP samples was determined using a texture analyser (Agrosta Texture Analyzer Version 2, Serqueux, France) with 5 kg load cell and 2 mm punch probe. High and low speeds were set to 1 mm/s and stroke after contact to 2 mm. Firmness was determined by measuring the maximum force (N) required to puncture the slices. The measurements were performed on two slices of each sample with 2 punctures on each slice and the results were expressed as mean value±SE.

**Colour analysis**

The colour of raw FCP slices was measured by a colorimeter (CR-5, Konica Minolta, Tokio, Japan), equipped with D65 light source and 2° standard observers using CIELAB colour parameters: L* (lightness), a* (red/green) and b* (yellow/blue). Measurements were performed on two slices of each sample and results were expressed as the mean value±SE.
Cooking treatments

Immediately after the treatment and on the 8th, 11th, 15th and 23rd day of storage, raw samples were cooked according to Dite Hunjek et al. (18). Boiling was performed in distilled water Φ(water, sample)=5:1 at 100 °C for 15 min. Frying was performed in sunflower oil \( m(\text{sample})/V(\text{oil})=120 \, \text{g/L} \) at initial temperature of 180 °C for 5 min. The surface moisture and oil of cooked potatoes were removed with paper towel.

Sensory monitoring

Quantitative Descriptive Analysis (QDA) of raw, boiled and fried potato samples was conducted in a sensory laboratory equipped according to the International Organization for Standardization (23) guidelines at ambient temperature (20 °C) by a panel of 6 trained people from the faculty and according to the ISO procedures 6564:1985 and 8586:2012 (24,25). Panellists had 3 day-training before the evaluation in order to acquaint with the product’s sensory descriptors and its evaluation. The panellists judged the quality and ranked each sample served at ambient temperature on coded plastic plates using a standard five-point scale from 1 (the lowest grade) to 5 (the highest grade) as described by Dite Hunjek et al. (5,18). Briefly, colour, as the browning intensity, was scored as: 1-no browning (white or cream), 2-no browning (yellow), 3-light browning, 4-average browning and 5-complete browning. Intensity of odour and off-odour was described as 1-absent to 5-very pronounced, moistness from 1-very dry to 5-very wet and firmness from 1-very soft to 5-very firm. Additional sensory attributes were evaluated in boiled and fried potatoes: potato-, sweet-, sour-, salty-, bitter- and off-taste from 1-absent to 5-very pronounced. Creaminess of boiled potato was scored from 1-absence of creamy texture to 5-melting in the mouth, while oiliness and crispness, as fried potato attributes, were graded with 1-absent to 5-very pronounced. All tested attributes are given in the tables as mean value±SE \((N=6)\).

Statistical analysis

The statistical analysis by parametric statistical tests was carried out to observe the effect of the UV-C treatment and storage time on the quality properties of raw, boiled and fried potato. The AMBC, SS, TS, pH, firmness, colour parameters, and sensory attributes were dependent measurable variables, while UV-C treatment and storage time were independent variables. Dependent variables were analysed by multivariate analysis of variance (MANOVA), while differences between specific group means (equal sample sizes) were determined by applying Tukey’s HSD test. The analysis was performed using Statistica v. 8.0 software (26). In order to examine possible grouping of the samples, Principal Component Analysis (PCA)
was performed on the correlation matrix using XLSTAT v. 5.1 software (27), wherein principal components (PC) with eigenvalue >1 and variables with communalities ≥0.5 were considered. The significance level for all tests was α≤0.05.

RESULTS AND DISCUSSION

Influence of UV-C treatment on permeance of packaging material

Although a slight increase of permeance of packaging material (1200 and 1300 cm³/(m²·day·kPa) was noticed for the samples 5-UV-C and 10-UV-C, respectively, this didn’t present real difference compared to the control (900 cm³/(m²·day·kPa) (data not presented). 3-UV-C showed identical value as control sample. The same conclusion was found by (28) for UV-C treated (46.7–746 mJ/cm for 0.5 to 8 min at 23 °C) PE film used for cucumber packaging. It was also found that UV-C transmittance through polymeric films depends on their characteristics (such as thickness, composition, level of crystallinity and number of layers in the film). Thus, for example PE film (24.7 μm) shows transmittance of 75.5 %, multilayer films composed of six or more layers exhibit 0 % transmission (29), while PA/PE laminate is 80 % permeable to UV-C (11) similar to polypropylene (PP) film (30). Although the effect of UV-C treatment on polymeric films has been investigated by few authors (30,31) it seems that this treatment does not affect barrier properties (28), while different observations were noticed for the mechanical and surface morphology of the polymers (29,31).

Aerobic mesophilic bacteria affected by UV-C treatment and storage time

The total AMBC in untreated and UV-C treated raw FCP during storage is presented in Fig. 1. Statistic results showed significant differences (p<0.01) in total AMBC between FCP samples. The initial microbial load of control sample was 2.30 log CFU/g. At the beginning of the storage, the lowest total AMBC was noticed in 10-UV-C samples (2.18 log CFU/g). When comparing all UV-C treatments with control throughout the storage period, the significant log reduction was present in 5- and 10-UV-C samples, especially till the 15th day. On that day measured values for 5- and 10-UV-C samples were 8.36 and 8.17 log CFU/g, respectively. Such results indicated that UV-C treatment longer than 5 min did not significantly improve the decontamination effect. Similar results were reported in study of Manzocco et al. (32) on FC melon cubes. The possible reason could be low UV-C light transmittance through the tissue and overshadowing of the microorganism on rough surface of the FC product (32,33). At the end of storage period, all applied UV-C treatments were equally effective on total AMBC reduction in FCP compared to the control. However, it should be mentioned that for this type of foodstuff (FCP intended for further cooking) there are no information provided by the EC
regulations (34,35) related to microbiological criteria regarding AMBC. Similarly, the Croatian Agency for Agriculture and Food (Guidelines for Assessing the Microbiological Safety of Ready-to-Eat Foods Placed on the Market) (36) issued borderline level of total AMBC only for ready-to-eat vacuum packed and refrigerated vegetables, and it is ≥10⁸ CFU/g.

(Fig. 1.)

Total solids, soluble solids and pH of FCP affected by UV-C treatment and storage time

As presented in Table 1, TS content was affected by UV-C treatment (p=0.046), while storage time did not have a significant influence (p=0.054). TS mean value of control sample was 21.70 %. The highest values were obtained in 10–UV-C samples (23.17 %) and generally at the 11th days of storage (23.08 %). With regard to the UV-C treatment, all treated samples had higher TS and it was observed that TS increased with UV-C dose increasing. The grand mean value of TS was 22.24 % what was quite similar to already reported (20.72 %) by Dite Hunjek et al. (5) for cv. Birgit potatoes (harvested in 2018). The slight differences could be a result of different treatment, as well as crop year or growing conditions (37). TS content obtained in the present study (grand mean of 22.24 %) represent acceptable value in terms of frying, considering that potatoes’ dry matter content of 20-24 % is appropriate for French fries (38). Higher potato dry matter will result in harder crust and drier potato inside texture (39).

However, the UV-C treatment and storage time had a significant influence (p≤0.01) on SS content, which varied from 4.18 to 4.80 °Bx (Table 1). In comparison with control (4.59 °Bx), the SS content decreased with increase of UV-C dosage, where 10-UV-C sample was attributed with the lowest value (4.30 °Bx). These results are in accordance with the results of Islam et al. (40) who performed UV-C treatment on tomatoes. This could be related with the impact of UV-C on conjugated structural bonds of some SS, which leads to their degradation or alteration (41). In present study, a significant decrease in SS content was observed after 8 days of storage (4.40 °Bx), after which it remained stable till the end of storage when it significantly increased. Kasim and Kasim (42) also reported oscillations of total SS during storage depending on applied dose of UV-C on fresh-cut melon cubes.

Considering pH, UV-C treatment and storage time significantly affected pH of raw FCP (p<0.01), which ranged from 5.42 to 5.99. When compared to the control (5.64) the lowest pH value was observed in 10-UV-C samples (5.57) and generally after 15 days of storage (5.42) (Table 1). With respect to UV-C treatment, pH decreased with increase of UV-C dosage similarly to the results of Islam et al. (2015), who also reported an increase of treated tomatoes titratable acidity with increase of UV-C doses. Moreover, pH also decreased during storage probably due to the respiration rate increase and CO₂ production what is in accordance with
the results of Dite Hunjek et al. (5) and Rocha et al. (43) studies. Lower pH can contribute to lower enzyme activity and consequently to the reduced intensity of browning (44). (Table 1)

**Firmness of FCP influenced by UV-C treatment and storage time**

Firmness was significantly affected by the UV-C treatment (p<0.01) with no significant effect of storage duration (p=0.14) (Table 1). The firmness grand mean value was 7.37 N, what is in accordance with the results for cv. Birgit (7.42 N) (18). Control sample was described with the highest firmness value (7.77 N) as well as the samples on the 8th day of storage (7.51 N). The firmness of FCP was lower in UV-C-treated samples compared to the control. However, increase of UV-C dose caused firmness increase what could be linked to the possible reduction of activity of plant cell wall degrading enzymes by UV-C light (45). A similar observation was also previously reported when FC pineapples were UV-C treated (46).

**Colour of FCP influenced by UV-C treatment and storage time**

The results of UV-C treatment and storage time influence on raw FCP colour parameters are shown in Table 1, where it can be observed that UV-C significantly affected only $L^*$ (p<0.01), while storage period had no significant effect on the colour during 23 days (p>0.05). The $L^*$ values were in range from 71.07 to 73.20, $a^*$ values from 1.38 to 1.98 and $b^*$ values from 38.37 to 40.49, respectively (Table 1). The lightness was considerably higher for 5-UV-C and 10-UV-C and lower for 3-UV-C samples than in control. The similar trend was also noticed in UV-C treated watermelon, where $L^*$ values increased with the increase of applied UV-C dose (33). This occurrence could be associated with UV-C light effect on inactivation of enzymes such as polyphenol oxidase or with reduced carotenoids content (47). Although in present study parameter $b^*$, whose positive values describe yellow colour and usually reflect a presence of carotenoids in potato (48), was not significantly reduced. Obtained FCP colour parameters are consistent with the European Cultivated Potato Database (49) data, where colour of tuber flesh cv. Birgit is listed as yellow and also very resistant to enzymatic browning.

**Sensory attributes of raw, boiled and fried FCP influenced by UV-C treatment and storage time**

**Raw FCP samples**

All sensory attributes of raw FCP were significantly affected by UV-C treatment and storage time (p<0.05), except moistness (p>0.05) (Table 2). Considering the UV-C treatment, the colour was rated from 1.58 in 3-UV-C to 1.98 in control, indicating negligible occurrence of browning. Furthermore, all UV-C treated samples showed a significant discoloration and were
graded as brighter than control, what is in accordance with previously discussed $L^*$ values (Table 1). Similar results were also reported by Manzocco et al. (32). The 10-UV-C samples showed more pronounced odour and less pronounced off-odour than other samples. All UV-C treated samples were less firm than control, but the most pronounced reduction in firmness was observed for 3–UV-C samples what is in accordance with the results measured by the instrument (Table 1).

During storage, potato colour was scored from 1.50 to 1.94 indicating no degradation in terms of browning. The odour was stable till the 15th day of storage but at the end of storage the development of off-odour was notable. The lowest firmness was observed at the beginning of the storage, but by the end of storage period FCP maintained uniform firmness. Generally, the results of this study showed that UV-C treatment preserved sensory attributes of colour, odour, moistness and firmness of raw FCP during 15 days of storage, however due to the off-odour development samples were not sensory acceptable at the end of storage.

(Table 2)

**Boiled FCP samples**

As it can be seen in Table 3, the majority of evaluated sensory attributes of boiled potatoes were significantly affected by UV-C treatment and storage duration ($p<0.05$). Sour-, bitter- and off-taste were not influenced by storage time as well as off-odour and moistness by UV-C treatment ($p>0.05$). Brighter colour was observed in all UV-C treated samples, equally as it was noticed in raw samples. The 5- and 10-UV-C samples had more intense boiled potato odour, sweet-, salty- and potato- taste. The desirable boiled potato flavour is a result of many naturally present characteristic compounds (glutamic and other amino acids) and ones produced during cooking (e.g. guanosine-5'-monophosphate and other 5'-ribonucleotides). Many other components such as methional, aliphatic alcohols and aldehydes also contribute to potato flavour. Besides, the desirable flavour of boiled potato derives from 2-isopropyl-3-methoxypyrazine, a compound with extremely low threshold present in raw and boiled potato (50-52). Obviously, UV-C treatment didn’t have a negative impact on that compounds, even stimulated their formation or better expression. All UV-C treated samples had lower firmness and more pronounced creaminess in comparison with the control, where higher decrease in firmness and increase in creaminess was noticed when applied UV-C dose increased. The increased UV-C treatment probably could induce some structural changes in the potato tissue, which can consequently be observed in a softer texture of the boiled potatoes. The softening degree of the boiled potatoes during cooking is influenced by starch characteristics such as amylose to amylopectin ratio, cell separation and cell wall softening (37). Some functional
properties of starch can be changed as a result of prolonged UV-C treatment, such as capability of absorbing and holding water during gelatinization, reduction in amylose contents, appearance of fracture and exocorrosion on the surface of the starch granule or a drop of crystallinity (53).

After the 15th day of storage browning was slightly more pronounced. Throughout the storage period the odour was highly rated, while the off-odour was more pronounced only at the end of storage period and it was less scored in boiled samples when compared to the raw samples. Such occurrence could be explained by the volatility of compounds responsible for off-odour of raw potato. This was also previously observed by Dite Hunjek et al. (5). The firmness and creaminess showed variations in scores during storage, however at the storage beginning firmness was rated with the lowest scores and creaminess achieved the highest scores. On the 11th day sweet taste was the most evident in comparison to other days, while a salty taste was more prominent on the 8th day. Generally, 5- and 10-UV-C boiled samples were characterised by desirable odour, creaminess and taste, as well as convenient colour and acceptable firmness. Such favourable sensory attributes were preserved for 23 days of storage.

(Table 3)

Fried FCP samples

The most of analysed sensory attributes of fried potato were significantly affected by UV-C treatment and storage time (p<0.01), with an exception of off-odour, crispiness, sour-, bitter- and off-taste (Table 4). Oiliness was significantly influenced only by storage time (p<0.01), but numerical differences were very slight (in a range from 1.00 to 1.13). In comparison with fried control samples, all UV-C treated samples had slightly brighter colour (2.11 to 2.15) after frying than control (2.33) and no browning between the samples was observed. According to the results of Sobol et al. (16) UV-C irradiation applied on potato tubers increased the brightness of the fried potatoes, what is in line with present results. Lin et al. (15) reported lower content of fructose and glucose in irradiated tubers during storage. During processing at high temperatures, reducing sugars and amino acids participate in Maillard’s reactions, which are responsible for colour and volatiles formation in fried products (54). Presumably, increased brightness could be linked to lowering of reducing sugars caused by UV-C treatment. Firmness of 10-UV-C samples significantly decreased, as it was observed in boiled ones (Table 3). Odour and potato-, sweet-, and salty- taste significantly increased in 10-UV-C fried potatoes. Potato taste intensity increased with applied UV-C dose, while potato off-taste was not pronounced, similarly as it is observed for boiled FCP.
Even though storage time showed a significant effect (p<0.01) on more than half of the evaluated properties, numerically differences were very slight. The browning scores were in range 2.00–2.52, and they were more pronounced on the 15th and 23rd day, like in boiled samples. Moreover, the sweet- and salty-taste of fried potatoes decreased and oiliness increased with storage time. The potato taste and odour were highly scored, as well as no off-odour was noticed independently of FCP storage duration. These results indicate that observed changes in off-odour in stored raw FCP have no influence on the odour of fried potatoes, what is in accordance with observations in boiled potatoes. Generally, UV-C treatments positively affected the taste, odour and colour formation in fried potatoes regardless of storage time.

(Table 4)

Results of PCA analysis in relation to the applied UV-C treatment and storage time

PCA was used to visualize relations between analysed parameters and to determine possible grouping of raw, boiled, and fried FCP samples in relation to the applied UV-C treatment and storage time (Fig. 2, Fig. 3 and Fig. 4). In terms of raw FCP samples, AMBC, pH, SS, L*, a*, b* and all sensory attributes except sensorial firmness were included in the test (Fig. 2). PC1 and PC2 together described 66.81 % of the total data variance, where PC1 correlated very strongly with AMBC (r=0.908), strongly with pH (r=-0.842) and moderately with browning intensity (r=0.686), odour (r=-0.678), off-odour (r=0.659) and moistness (r=-0.672). On the other hand, PC2 showed a very strong correlation with SS (r=0.848) and $b^*$ (r=-0.826) and strong correlation with $L^*$ (r=-0.778) and $a^*$ (r=-0.743), while moderate correlation was present between this PC and odour (r=-0.453) as well as off-odour (r=0.444). Considering UV-C treatments duration, the results showed certain grouping of the samples, where almost all 5- and 10-UV-C raw treated samples were placed at negative PC2 values being characterized with higher scores for colour parameters and odour. Moreover, 3-UV-C samples did not distinguish as a separate group, while 0-UV-C samples distributed mainly at positive PC1 and PC2 values. Furthermore, grouping was observed in relation to storage time, where all samples from the 23rd day of storage were also placed in the upper right quadrant being characterized by higher levels of AMBC, browning and off-odour. 0-UV-C samples from the 11th and 15th storage day were also positioned in this part of the factorial plane.

(Fig. 2)
Considering the boiled FCP samples, browning intensity, odour, moistness, sensorial firmness, creaminess, potato taste and bitterness were selected as PCA active variables and PC1 and PC2 explained 63.92% of the total data variance (Fig. 3). PC1 showed a strong correlation with browning intensity ($r=-0.750$), creaminess ($r=0.699$), potato taste ($r=0.770$), sweetness ($r=0.626$), saltiness ($r=0.611$) and bitterness ($r=-0.746$) as well as a moderate correlation with off-odour ($r=-0.501$), while a strong/moderate correlation was present between PC2 and off-odour ($r=0.602$), creaminess ($r=0.430$), saltiness ($r=0.402$) as well as bitterness ($r=0.493$). Clear separation of the samples can be noticed with regard to UV-C treatment. The major distinction of the samples was observed for 10-UV-C treated samples, which were distributed at the positive values of PC1 and PC2 and were characterized by positive sensorial attributes - creaminess, saltiness, sweetness and characteristic potato taste. On the other hand, almost all control samples were placed at negative values of PC1 and PC2. Also, 3- and 5-UV-C samples were situated around the centre of the factorial plane. Besides, FCP boiled on the 23rd storage day were again separated by negative PC1 values, which were correlated to scores for browning intensity, bitterness and off-odour which were especially high in the control sample.

(Fig. 3)

As for fried potato samples, browning intensity, off-odour, oiliness, sensorial firmness, potato taste, sweetness, saltiness, bitterness and off-taste were considered and first two PC described 81.03% of the total data variance (Fig. 4). A very strong/strong correlation was present between browning intensity ($r=0.918$), off-odour ($r=0.918$), bitterness ($r=0.962$), off-taste ($r=0.969$), oiliness ($r=0.783$) and PC1, while PC2 correlated strongly/very strongly with sensorial firmness ($r=-0.838$), sweetness ($r=0.895$), saltiness ($r=0.901$) and potato taste ($r=0.654$). The grouping of the fried potato samples in terms of UV-C treatment is rather poor, where only 10-UV-C samples, being described with sweetness, saltiness and potato taste, slightly distinguished from the rest of the samples, especially from the samples fried at the beginning of the storage (1st and 8th day). Again, control sample from the 23rd day of storage separated from the rest of the samples according to the higher scores for undesirable sensory attributes, i.e. browning, oiliness, off-taste, bitterness and off-odour.

(Fig. 4)

CONCLUSIONS

UV-C technology is promising and it have potential practical application in fresh-cut industry, especially since it has been already approved for application in food industry.
specifically for liquid systems or surface disinfection. Further, it is considered as environmentally friendly with low costs of energy, equipment, and maintenance.

The results of this study could contribute to UV-C application in fresh-cut industry since UV-C treatment in combination with SA and vacuum packaging showed high efficiency in reduction of microbial count in raw FCP cv. Birgit during storage at (6±1) °C and in extension of its shelf-life. UV-C treatments of 5 and 10 min were particularly effective. Generally, good quality and sensory attributes of FCP retained up to 15 days of storage. UV-C treatment contributed to the reduction of FCP browning and affected odour of raw FCP positively, and acceptable firmness was retained as well. Furthermore, UV-C treated FCP after boiling and frying were also sensorially desirable as they were characterized with more pronounced characteristic potato odour and taste in comparison with untreated FCP.

In possible real FCP scale, UV-C treatment could present relatively short additional operation for ensuring safety and extended shelf-life. Namely, it could be the final operation after potato slicing, treatment by ABA (e.g. SA solution) and after vacuum packaging. However, further investigation is needed in order to determine all parameters necessary to confirm the use of UV-C technology on a real scale in the FCP industry.

FUNDING

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CONFLICT OF INTEREST

Authors declare no conflict of interest.

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B. Levaj https://orcid.org/0000-0002-0425-4847
AUTHORS’ CONTRIBUTION

Zdenka Pelaić performed the experiment, analysed data, conducted and interpreted statistical analysis and drafted the original manuscript; Zrinka Čošić, contributed in performing experiment and editing manuscript; Kata Galić and Mario Ščetar contributed in performing experiment; Maja Repajić contributed in conduction and interpretation of the statistical data as well as revised the manuscript; Sandra Pedisić participated in writing original draft; Zoran Zorić participated in formal analysis; Branka Levaj developed and conceptualized the idea and methodology of the study, contributed in data interpretation as well as revised the manuscript.

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Table 1. The influence of UV-C treatment and storage time on soluble and total solids, pH, firmness and colour parameters of raw fresh-cut potatoes

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>w(total solids)/%</th>
<th>TSS/Brix</th>
<th>pH</th>
<th>Firmness/N</th>
<th>L*</th>
<th>a*</th>
<th>b*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>p=0.05*</td>
<td>p=0.01*</td>
<td>p&lt;0.01*</td>
<td>p&lt;0.01*</td>
<td>p&lt;0.01*</td>
<td>p=0.22</td>
<td>p=0.33</td>
</tr>
<tr>
<td>Control</td>
<td>(21.70±0.37)a</td>
<td>(4.59±0.06)b</td>
<td>(5.64±0.01)c</td>
<td>(7.77±0.09)c</td>
<td>(71.77±0.43)ab</td>
<td>(1.62±0.23)a</td>
<td>(40.02±0.89)a</td>
</tr>
<tr>
<td>3-UV-C</td>
<td>(21.90±0.37)ab</td>
<td>(4.58±0.06)ab</td>
<td>(5.63±0.01)bc</td>
<td>(7.00±0.09)a</td>
<td>(71.07±0.43)a</td>
<td>(1.38±0.23)a</td>
<td>(38.37±0.89)a</td>
</tr>
<tr>
<td>5-UV-C</td>
<td>(22.19±0.37)ab</td>
<td>(4.44±0.06)a</td>
<td>(5.59±0.01)ab</td>
<td>(7.35±0.09)ab</td>
<td>(73.20±0.43)b</td>
<td>(1.98±0.23)a</td>
<td>(40.32±0.89)a</td>
</tr>
<tr>
<td>10-UV-C</td>
<td>(23.17±0.37)c</td>
<td>(4.30±0.06)a</td>
<td>(5.57±0.01)a</td>
<td>(7.37±0.09)ab</td>
<td>(72.99±0.43)b</td>
<td>(1.98±0.23)a</td>
<td>(40.49±0.89)a</td>
</tr>
<tr>
<td>t(storage)/days</td>
<td>p=0.05</td>
<td>p&lt;0.01*</td>
<td>p&lt;0.01*</td>
<td>p=0.14</td>
<td>p=0.38</td>
<td>p=0.10</td>
<td>p=0.25</td>
</tr>
<tr>
<td>0</td>
<td>(21.86±0.41)a</td>
<td>(4.80±0.07)b</td>
<td>(5.99±0.01)d</td>
<td>(7.44±0.11)a</td>
<td>(71.60±0.48)a</td>
<td>(1.67±0.26)a</td>
<td>(40.67±0.99)a</td>
</tr>
<tr>
<td>8</td>
<td>(21.82±0.41)a</td>
<td>(4.40±0.07)a</td>
<td>(5.62±0.01)c</td>
<td>(7.51±0.11)a</td>
<td>(72.81±0.48)a</td>
<td>(2.19±0.26)a</td>
<td>(39.86±0.99)a</td>
</tr>
<tr>
<td>11</td>
<td>(23.08±0.41)a</td>
<td>(4.26±0.07)a</td>
<td>(5.51±0.01)b</td>
<td>(7.45±0.11)a</td>
<td>(71.88±0.48)a</td>
<td>(1.29±0.26)a</td>
<td>(39.56±0.99)a</td>
</tr>
<tr>
<td>15</td>
<td>(21.57±0.41)a</td>
<td>(4.18±0.07)a</td>
<td>(5.42±0.01)c</td>
<td>(7.15±0.11)a</td>
<td>(72.61±0.48)a</td>
<td>(2.09±0.26)a</td>
<td>(40.99±0.99)a</td>
</tr>
<tr>
<td>23</td>
<td>(22.86±0.41)a</td>
<td>(4.75±0.07)b</td>
<td>(5.50±0.01)b</td>
<td>(7.31±0.11)a</td>
<td>(72.39±0.48)a</td>
<td>(1.47±0.26)a</td>
<td>(37.93±0.99)a</td>
</tr>
<tr>
<td>Grand mean</td>
<td>22.24</td>
<td>4.48</td>
<td>5.61</td>
<td>7.37</td>
<td>72.24</td>
<td>1.74</td>
<td>39.80</td>
</tr>
</tbody>
</table>

*aStatistically significant variable at α≤0.05. Results are expressed as mean±SE. Different letters mean statistically different values at α≤0.05.
Table 2. The influence of UV-C treatment and storage time on sensory properties of raw fresh-cut potatoes

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>Browning</th>
<th>Odour</th>
<th>Off-odour</th>
<th>Moistness</th>
<th>Firmness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>p&lt;0.01*</td>
<td>p&lt;0.01*</td>
<td>p&lt;0.01*</td>
<td>p=0.09</td>
<td>p=0.03*</td>
</tr>
<tr>
<td>Control</td>
<td>(1.98±0.04)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>(3.40±0.03)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>(1.53±0.03)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>(1.55±0.02)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>(4.97±0.05)&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>3-UV-C</td>
<td>(1.58±0.04)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>(3.47±0.03)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>(1.53±0.03)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>(1.52±0.02)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>(4.75±0.05)&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>5-UV-C</td>
<td>(1.66±0.04)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>(3.48±0.03)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>(1.43±0.03)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>(1.50±0.02)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>(4.82±0.05)&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
<tr>
<td>10-UV-C</td>
<td>(1.65±0.04)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>(3.67±0.03)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>(1.17±0.03)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>(1.50±0.02)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>(4.85±0.05)&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
<tr>
<td>t(storage)/days</td>
<td>p&lt;0.01*</td>
<td>p&lt;0.01*</td>
<td>p&lt;0.01*</td>
<td>p=0.06</td>
<td>p=0.01*</td>
</tr>
<tr>
<td>0</td>
<td>(1.50±0.05)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>(4.00±0.04)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>(1.00±0.03)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>(1.56±0.02)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>(4.65±0.06)&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>8</td>
<td>(1.50±0.05)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>(4.00±0.04)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>(1.00±0.03)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>(1.52±0.02)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>(4.92±0.06)&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>11</td>
<td>(1.73±0.05)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>(3.98±0.04)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>(1.00±0.03)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>(1.50±0.02)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>(4.90±0.06)&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>15</td>
<td>(1.94±0.05)&lt;sup&gt;c&lt;/sup&gt;</td>
<td>(3.98±0.04)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>(1.02±0.03)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>(1.50±0.02)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>(4.88±0.06)&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>23</td>
<td>(1.94±0.05)&lt;sup&gt;c&lt;/sup&gt;</td>
<td>(1.56±0.04)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>(3.06±0.03)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>(1.50±0.02)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>(4.90±0.06)&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Grand mean</td>
<td>1.72</td>
<td>3.51</td>
<td>1.42</td>
<td>1.52</td>
<td>4.85</td>
</tr>
</tbody>
</table>

*Statistically significant variable at α≤0.05. Results are expressed as mean±SE. Different letters mean statistically different values at α≤0.
**Table 3.** The influence of UV-C treatment and storage time on sensory properties of boiled fresh-cut potatoes

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>Browning</th>
<th>Odour</th>
<th>Off-odour</th>
<th>Moistness</th>
<th>Firmness</th>
<th>Creaminess</th>
<th>Potato taste</th>
<th>Sweet taste</th>
<th>Sour taste</th>
<th>Salty taste</th>
<th>Bitter taste</th>
<th>Off-taste</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>p&lt;0.01*</td>
<td>p&lt;0.01*</td>
<td>p=0.17</td>
<td>p=0.70</td>
<td>p&lt;0.01*</td>
<td>p&lt;0.01*</td>
<td>p&lt;0.01*</td>
<td>p&lt;0.01*</td>
<td>p=0.39</td>
<td>p&lt;0.01*</td>
<td>p=0.53</td>
<td>p=0.57</td>
</tr>
<tr>
<td>Control</td>
<td>(2.40±0.05)c</td>
<td>(4.70±0.03)a</td>
<td>(2.07±0.03)a</td>
<td>(2.30±0.08)c</td>
<td>(3.70±0.07)a</td>
<td>(4.35±0.05)a</td>
<td>(1.05±0.04)a</td>
<td>(1.05±0.03)a</td>
<td>(1.00±0.04)a</td>
<td>(1.03±0.02)a</td>
<td>(1.00±0.01)a</td>
<td></td>
</tr>
<tr>
<td>3-UV-C</td>
<td>(1.95±0.05)a</td>
<td>(4.76±0.03)a</td>
<td>(2.08±0.03)a</td>
<td>(1.97±0.08)b</td>
<td>(4.23±0.07)b</td>
<td>(4.93±0.05)b</td>
<td>(1.12±0.04)bc</td>
<td>(1.00±0.03)a</td>
<td>(1.00±0.04)a</td>
<td>(1.00±0.02)a</td>
<td>(1.00±0.01)a</td>
<td></td>
</tr>
<tr>
<td>5-UV-C</td>
<td>(2.13±0.05)b</td>
<td>(4.92±0.03)b</td>
<td>(2.12±0.03)b</td>
<td>(1.72±0.08)b</td>
<td>(4.38±0.07)b</td>
<td>(4.92±0.05)b</td>
<td>(1.23±0.04)b</td>
<td>(1.03±0.03)a</td>
<td>(1.20±0.04)b</td>
<td>(1.00±0.02)a</td>
<td>(1.02±0.01)a</td>
<td></td>
</tr>
<tr>
<td>10-UV-C</td>
<td>(2.03±0.05)b</td>
<td>(5.00±0.03)b</td>
<td>(2.10±0.03)a</td>
<td>(1.12±0.08)b</td>
<td>(4.72±0.07)c</td>
<td>(4.92±0.05)b</td>
<td>(1.45±0.04)c</td>
<td>(1.00±0.03)a</td>
<td>(1.50±0.04)b</td>
<td>(1.02±0.02)a</td>
<td>(1.02±0.01)a</td>
<td></td>
</tr>
<tr>
<td>t(storage)/days</td>
<td>p&lt;0.01*</td>
<td>p&lt;0.01*</td>
<td>p&lt;0.01*</td>
<td>p&lt;0.01*</td>
<td>p&lt;0.01*</td>
<td>p&lt;0.01*</td>
<td>p&lt;0.01*</td>
<td>p&lt;0.01*</td>
<td>p&lt;0.01*</td>
<td>p&lt;0.01*</td>
<td>p=0.13</td>
<td>p=0.10</td>
</tr>
<tr>
<td>0</td>
<td>(1.50±0.05)a</td>
<td>(5.00±0.04)c</td>
<td>(2.00±0.03)a</td>
<td>(1.46±0.09)a</td>
<td>(4.58±0.07)b</td>
<td>(4.69±0.05)a</td>
<td>(1.10±0.05)a</td>
<td>(1.00±0.03)a</td>
<td>(1.08±0.05)ab</td>
<td>(1.00±0.02)a</td>
<td>(1.00±0.01)a</td>
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</tr>
<tr>
<td>8</td>
<td>(1.92±0.05)b</td>
<td>(4.52±0.04)c</td>
<td>(2.17±0.03)b</td>
<td>(2.10±0.09)b</td>
<td>(4.13±0.07)b</td>
<td>(4.83±0.05)a</td>
<td>(1.06±0.05)a</td>
<td>(1.00±0.03)a</td>
<td>(1.48±0.05)c</td>
<td>(1.00±0.02)a</td>
<td>(1.00±0.01)a</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>(1.67±0.05)a</td>
<td>(5.00±0.04)c</td>
<td>(2.30±0.03)b</td>
<td>(1.83±0.09)bc</td>
<td>(4.23±0.07)b</td>
<td>(4.88±0.05)a</td>
<td>(1.75±0.05)b</td>
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</tr>
<tr>
<td>15</td>
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<td>(5.00±0.04)c</td>
<td>(2.00±0.03)a</td>
<td>(1.58±0.09)ab</td>
<td>(4.23±0.07)b</td>
<td>(4.85±0.05)a</td>
<td>(1.10±0.05)a</td>
<td>(1.04±0.03)a</td>
<td>(1.04±0.05)a</td>
<td>(1.00±0.02)a</td>
<td>(1.00±0.01)a</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>(2.92±0.05)d</td>
<td>(4.73±0.04)b</td>
<td>(2.00±0.03)a</td>
<td>(1.90±0.09)bc</td>
<td>(4.13±0.07)b</td>
<td>(4.65±0.05)a</td>
<td>(1.04±0.05)a</td>
<td>(1.06±0.03)a</td>
<td>(1.00±0.05)a</td>
<td>(1.06±0.02)a</td>
<td>(1.04±0.01)a</td>
<td></td>
</tr>
<tr>
<td>Grand mean</td>
<td>2.13</td>
<td>4.85</td>
<td>1.05</td>
<td>2.09</td>
<td>1.78</td>
<td>4.26</td>
<td>4.78</td>
<td>1.21</td>
<td>1.02</td>
<td>1.18</td>
<td>1.01</td>
<td>1.01</td>
</tr>
</tbody>
</table>

*Statistically significant variable at α≤0.05. Results are expressed as mean±SE. Different letters mean statistically different values at α≤0.05.
Table 4. The influence of UV-C treatment and storage days on sensory properties of fried fresh-cut potatoes

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>Browning</th>
<th>Odour</th>
<th>Off-odour</th>
<th>Oiliness</th>
<th>Firmness</th>
<th>Crispiness</th>
<th>Potato taste</th>
<th>Sweet taste</th>
<th>Sour taste</th>
<th>Salty taste</th>
<th>Bitter taste</th>
<th>Off-taste</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>p&lt;0.01*</td>
<td>p&lt;0.01*</td>
<td>p=0.53</td>
<td>p=0.85</td>
<td>p&lt;0.01*</td>
<td>p=0.53</td>
<td>p&lt;0.01*</td>
<td>p&lt;0.01*</td>
<td>p=0.53</td>
<td>p&lt;0.01*</td>
<td>p=0.56</td>
<td>p=0.53</td>
</tr>
<tr>
<td>Control</td>
<td>(2.33±0.03)B</td>
<td>(4.63±0.04)A</td>
<td>(1.03±0.02)A</td>
<td>(1.07±0.03)A</td>
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<td>p&lt;0.01*</td>
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*Statistically significant variable at α≤0.05. Results are expressed as mean±SE. Different letters mean statistically different values at α≤0.05.
Fig. 1. The total count of aerobic mesophilic bacteria of untreated and UV-C treated raw fresh-cut potatoes during storage, expressed as mean values of log CFU/g; (p<0.01, α≤0.05)
Fig. 2. Biplot related to the raw fresh-cut potatoes [AMBC=aerobic mesophilic bacteria count, SS=soluble solids; first number in the sample label indicates UV-C treatment (min) and second number indicates storage day]
Fig. 3. Biplot related to the boiled fresh-cut potatoes [first number in the sample label indicates UV-C treatment (min) and second number indicates storage day]
Fig. 4. Biplot related to the fried fresh-cut potatoes [first number in the sample label indicates UV-C treatment (min) and second number indicates storage day]