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A COMBINED METHOD OF POSTHARVEST HANDLING OF SWEET CHERRY FRUITS IMPROVES FRUIT STORABILITY

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ABSTRACT

The objective of the research was to determine an optimum method of postharvest handling of sweet cherry fruits which may contribute to prolonged shelf-life. The following physical factors were examined – storage temperature: 2–4°C, 6–8°C, 18–20°C; postharvest fruit packaging and treatment: Xtend® CH-49 bags + no exposure to UV-C, Xtend® + exposure to UV-C for 120 s or 600 s, no bagging + no exposure to UV-C, no bagging + UV-C for 120 s or 600 s. UV-C irradiation, regardless of the duration and storage conditions, prolonged the storage life of sweet cherry fruit. During the 14-day period of storage, the smallest weight loss as well as the highest number of fruits suitable for consumption were found after exposure to UV-C for 600 s in both Xtend® bags and flat, exposed polyethylene containers. After 28 days, higher amount of fruits suitable for consumption were found after storage at 2–4°C than at 6–8°C. The most advantageous postharvest treatment method was placing fruits in containers and irradiating them with UV-C for 600 s. However, statistically similar results were obtained also after packing the fruits in Xtend® bags and irradiating them with UV-C for 600 s as well as placing them in containers and irradiation with UV-C for 120 s. In addition, UV-C irradiated fruits for 120 s and 600 s contained significantly more reducing sugars than non-irradiated fruits after 14 days of storage. UV-C irradiated fruits for 600 s also contained the greatest amount of flavonoids. After 28 days of storage, the highest content of flavonoids and phenols was determined in UV-C exposed fruits stored in containers. In addition, it emerged that storing sweet cherry fruit at 2–4°C without bagging contributed to increased total phenolic content compared with fruit stored in Xtend® bags. Packaging cherry fruit in Xtend® bags is the most reasonable when it stored at 6–8°C and at room temperature.

Key words: Xtend MAP bags, UV-C irradiation, sugars, ascorbic acid, phenolic, food safety

INTRODUCTION

UV-C irradiation is a method of removal of viruses, bacteria and fungi and is frequently applied to disinfect non-resistant to high temperatures materials, or the ones which cannot be treated with chemicals [Kashiwabuchi et al. 2012]. Advances in technology have shown that UV radiation treatment of vegetables or fruit may be a way for the extension of their shelf-life [Adetuyi et al. 2018, Michailidis et al. 2019, Abdipour et al. 2020]. According to Tomaszewska-Sowa et al. [2015] a high degree of plant material sterilisation may be achieved by exposure to UV-C which wavelength ranges from 100 to 280 nm. This method is successfully applied to sterilise surfaces in the biopharmaceutical industry [Yen et al. 2014], or postharvest to protect plant raw materials [Mercier et al. 2001, Formica-Oliveira et al. 2017, Araque et al. 2018,

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Michailidis et al. 2019]. Advances in technology have shown that UV radiation treatment of vegetables or fruit may be a way for the extension of their shelf-life [Wang et al. 2009, Escalona et al. 2010, Darvishi et al. 2012, Adetuyi et al. 2018]. UV-C irradiation results in a number of benefits for producers as it does not leave any residues in the food treated, is cheap and easy to use, and is effective at removing most of the microorganisms [Bintsis et al. 2000]. Germ inactivation may be achieved within several seconds to several minutes, depending on foodstuff transparency and germ type [Marquenie et al. 2002, Krishnamurthy 2006]. In addition to bactericidal activity, UV radiation has been demonstrated to cause desirable changes in the composition of fruit and vegetables, for example an increase in anti-oxidative value [Wang et al. 2009, Zhang and Jiang 2019, Abdipour et al. 2020].

Another method of reducing the number of microorganisms on fresh fruit and vegetable surfaces, and extending their storage life is to apply packaging which modifies the micro-atmosphere around the product packed in it [Irtwange 2006, Abadias et al. 2012, Aglar et al. 2017]. Fruit and vegetable storage in packaging which modifies the atmosphere inhibits the development of microorganisms causing the decay of products, delays processes associated with postharvest ripening, contributes to lower water losses, and reduces changes in the texture following water loss such as shrinking and wilting. The effectiveness of modified atmosphere is affected by factors such as product type, temperature and properties of the packaging material [Sandhya 2010, Caleb et al. 2012, Giuggioli et al. 2015, Cui et al. 2019].

The objective of the study was to determine an optimum method of postharvest sweet cherry handling which may contribute to extended cherry fruit shelf-life. To that end, the effect of varied timings of fruit exposure to UV-C combined with the fruit storage in Xtend® bags under different thermal conditions on fruit suitability for consumption and the content of selected nutrients were examined.

MATERIALS AND METHODS

Plant material. An experiment was conducted on the fruits of sweet cherry (*Prunus avium* L.) cv. Summit harvested on 29th June 2016. The indicator determining the date of harvest was the skin color, typically for this variety. Skin colour has been accepted as the best indicator for the appropriate harvest maturity of sweet cherries for a long time [Drake and Elfving 2002]. The five-year-old cherry trees grew in an orchard in Żanecin located in east-central Poland (52°23'N; 22°15'N).

Experimental factors and samples preparation. A laboratory experiment (Laboratory of the Department of Vegetable Crops of Siedlce University of Natural Sciences and Humanities, Poland) was carried out in a completely randomised design with three replicates. The effect of the following physical factors was examined:

A) storage temperature: cold storage at 2–4°C, fridge 6–8°C, room temperature 18–20°C;

B) postharvest handling: Xtend® bags + no exposure to UV-C (B-UV0), Xtend® bags + exposure to UV-C for 120 s (B-UV120), Xtend® bags + exposure to UV-C for 600 s (B-UV 600), no bags or exposure to UV-C (NB-UV0), no bags + exposure to UV-C for 120 s (NB-UV120), no bags + exposure to UV-C for 600 s (NB-UV600).

A total of 54 samples were prepared using fruit with pedicels. Each sample, weighing 585 ±6.81 g, consisted of 50 healthy, non-cracked and mechanically non-damaged fruit. One half of the samples were packaged in Xtend® CH-49 modified atmosphere packaging bags (B), the second half of samples were kept in flat polythene containers (NB), with dimensions of 120 × 170 mm. The height of the containers was 60 mm. The bagged and non-bagged samples were divided into three parts, each part containing 18 samples. One part was exposed to UV-C irradiation for 120 s, another for 600 s and the remaining part was non-treated. Each sample in bags and containers was irradiated separately. Cherry fruits in sacks and containers were arranged in one layer. Bagged fruits and containers were placed for storage at various temperatures. At this stage of the experiment, a reference sample was analysed to determine the content of selected nutrients which later were used for comparison with fresh fruit content of the nutrients as well as nutrient concentrations in fruit treated with the experimental factors and after the storage periods described in the methodology.

Xtend® bags. Fruit were stored in Xtend® modified atmosphere packaging bags (CH-49) manufactured

by StePac L.A. Ltd. headquartered in Tefen, Israel. Xtend® bags modify the micro-atmosphere around the product packaged in them thus contributing to a decline in oxygen content, an increase in carbon dioxide content, an increase in humidity, and making possible to control water vapour condensation. Modified atmosphere and relative humidity of 90–95%, obtained as a result of respiration of product stored in Xtend® bags, reduces dehydration and weight loss to a minimum, and ensures the product firmness. At the same time, Xtend® bags remove excess moisture, which results in the product which preserves its freshness, healthy appearance, and prevents physiological disturbances [Irtwange 2006].

The dimensions of the Xtend® bags used in the experiment were 315 × 410 mm. After packing the cherry fruit, the bags were tightly closed with a special clip to prevent air from entering the interior.

UV-C irradiation. Irradiation of the fruit was achieved by using two lamps (TUV 36W/G36 T8 Philips Eindhoven, The Netherlands), at the wavelength of 256 nm. Both lamps were installed in a casing with a reflector made of stainless steel. Exposure to UV-C consisted of two cycles, 60 s each (in total 120 s) or two cycles, 300 s each (in total 600 s). Fruits were placed at a distance of 40 cm from the irradiation source. After the first treatment, the fruits were shuffled to increase the area of exposure to the ultraviolet radiation.

Fruit packaged in Xtend® bags were irradiated after bagging, through the polythene layer which was a physical barrier limiting the amount of radiation reaching the fruit surface. Non-bagged fruits were loosely placed in non-covered flat containers measuring 17 × 12 × 10 cm imitating the conditions of storage in crates. In the containers, there was a direct exposure of the fruits to radiation.

UV-C radiation intensity was measured by means of UV LightMeter SENTRY® ST512 (Taiwan, China). These instruments are designed to measure ultraviolet light in the range from 220 to 275 nm (UVC), 320 to 380 nm (UVA) and 280 to 400 nm (UVAB). The good illumination range of each kind of meter allow users to conduct the most precise quantitative measurements of ultraviolet radiation. During exposure to UV-C radiation lasting for 120 s and 600 s, radiation rates for non-bagged fruit were 1.03 and 5.16 kJ·m^{-2}, respectively, and for fruit stored in Xtend® bags, 0.85 and 4.25 kJ·m^{-2}, respectively. The measurement was made using a sensor attached to the LightMeter SENTRY® ST512 UV meter. The sensor was placed at the same distance from the lamp as the samples were placed. To measure the radiation intensity that reached the cherry fruit packed in Xtend® bags, the sensor was also placed inside the bags. The exposure time was 120 s and 600 s.

Observations and analyses. Observations and measurements of fruit stored at 2–4°C and 6–8°C were taken after 14 and 28 days after exposure to UV-C. At the temperature of 18–20°C, observations were made after 14 days only because the conditions of fruit storage made it impossible to continue the testing. The number and weight of fruits suitable for consumption were taken during observation. Fruits described as "for consumption" were firm fruits, without stains on the surface and no signs of rot and mold.

The fruit samples (after harvesting) were taken to perform chemical analyzes for their dry mass content, reducing sugars, ascorbic acid, phenols and flavonoids. The same analyzes were performed after 14 days for fruit stored at room temperature, and after 28 days for the products kept in a cold room and a fridge, for each combination of postharvest treatment (n = 3 from each combination).

Determination of dry matter. Dry matter determination was conducted by the gravimetric method following AOAC (AOAC 2005). The pits or stones were removed from the fruits, then the fruits was predried. For this purpose 50 g of each sample was prepared and dried at 60°C to reach the humidity level of 8–10%. The samples were air-cooled for 1 hour and weighed to an accuracy of 0.01 g. 5 g of a sample was taken from the air-dry ground material and placed in a container with a lid. The samples were dried at 103°C until the absolute difference between dry matter values at two successive weight measurements was no more than 0.01%. Dry matter (DM) content was calculated following the formula:

$$DM = \frac{Wd}{Wi} \times 100\ (\%),$$

in which Wd – weight (g) of a sample after drying, Wi – initial weight (g) of the sample. The drying index (D index) was calculated according to the formula:

$$D\ index = \frac{Wd}{W'},$$

where Wd – weight (g) of a sample after drying, W' – sample weight (g) prior to initial drying, and the dry matter of sample subjected to drying DMx = DM × D index (%).

Determination of reducing sugars. The total soluble sugars were determined by the Luff-Schoorl method (Polish Standard PN-90/A-75101/07).

Determination of L-ascorbic acid. The determination was carried out Tillmans method which consists in reduction of dyed 2,6-Dichloroindophenol to a colourless leuco-compound by acid solution of ascorbic acid. Fruit samples were homogenised. 10 g of the homogenate was weighed, and 2% solution of oxalic acid was added to obtain a volume of 100 cm^3. The samples were placed in a dark place for 15 min and then filtered. 10 cm^3 of the filtrate was taken and titrated with a solution of 2,6-Dichloroindophenol until a slightly pink colour persisting for about 10 s had been observed. L-ascorbic acid content (AA, mg per 100 g) was calculated according to the formula:

$$AA = \frac{\text{volume of 2.6 DPIP used } (cm^3) \times \text{standard concentration of 2.6 DPIP used} \times 100}{\text{volume of solution used for titration } (cm^3) \times \text{sample weight in 1 } cm^3 \text{ of the solution examined (g)}}.$$

Table 1. Weight of fruit suitable for consumption (g)

Postharvest handling (B)	Storage temperature (A)			Mean
	2–4°C	6–8°C	18–20°C	
After 14 days of storage				
B-UV0	533.3 ±13.01^{a}	525.9 ±5.55^{a}	198.0 ±26.34^{a}	419.1 ±166.49^{ab}
B-UV120	538.1 ±15.71^{a}	531.5 ±19.15^{a}	206.0 ±25.44^{a}	425.2 ±165.36^{ab}
B-UV600	552.1 ±9.95^{a}	559.3 ±21.57^{a}	224.3 ±35.69^{a}	445.3 ±167.14^{b}
NB-UV0	544.5 ±3.75^{a}	504.2 ±24.01^{a}	138.6 ±72.22^{a}	395.8 ±197.37^{a}
NB-UV120	562.9 ±3.56^{a}	541.1 ±14.58^{a}	162.8 ±19.46^{a}	422.2 ±195.24^{ab}
NB-UV600	567.3 ±5.78^{a}	541.1 ±7.80^{a}	213.3 ±30.24^{a}	440.5 ±174.07^{b}
Mean	549.7 ±15.18^{B}	533.9 ±23.40^{B}	190.5 ±45.05^{A}	
ANOVA	*F*	*P*	$LSD_{0.05}$	
A	567.18	<0.001	39.93	
B	6.42	<0.001	32.38	
A × B	2.24	>0.05	ns	
After 28 days of storage				
B-UV0	283.4 ±78.98^{a}	245.9 ±36.42^{a}	–	264.6 ±58.73^{a}
B-UV120	361.3 ±47.66^{b}	253.6 ±21.34^{a}	–	307.5 ±67.59^{ab}
B-UV600	381.0 ±7.92^{bc}	339.4 ±7.73^{b}	–	360.2 ±23.86^{bc}
NB-UV0	344.8 ±25.02^{b}	263.5 ±11.44^{a}	–	304.2 ±47.81^{ab}
NB-UV120	414.0 ±37.71^{cd}	257.3 ±4.99^{a}	–	335.7 ±89.14^{bc}
NB-UV600	436.4 ±13.56^{d}	320.1 ±11.18^{b}	–	378.3 ±64.69^{c}
Mean	370.2 ±62.13^{B}	280.0 ±40.27^{A}	–	
ANOVA	*F*	*P*	$LSD_{0.05}$	
A	220.33	<0.001	17.11	
B	5.63	<0.001	63.82	
A × B	5.09	<0.001	45.75	

Abbreviations – see at section Materials and Methods
Each values are mean ±standard deviation, $n = 3$
Mean ±SD followed by different lowercase letters in columns and different uppercase letters in columns differ significantly at $p \leq 0.05$
F – F-distribution, *P* – probability, $LSD_{0.05}$ – least significant difference, ns – not significant

Determination of phenolics and flavonoids. Total phenolics content was determined with the Folin-Ciocalteu reagent [Stratil et al. 2006]. 25 g of fresh sweet cherry was extracted with methanol (80%) and defatted with petroleum ether. The solution (0.2 ml) was mixed with 6.8 ml of deionized water and 0.5 ml of 50% Folin-Ciocalteu reagent. After incubation for 3 min 2.0 ml of 20% sodium carbonate (Na_2CO_3) was added and water was added to the final volume of 10 ml. The absorbance of the dark blue product was measured at 725 nm (Lambda 25 spectrophotometer, PerkinElmer, Inc., Waltham, MA, USA). Gallic acid (Sigma-Aldrich) was used as the standard. The concentration of total flavonoids was measured by the aluminum chloride colorimetric method described by Czapski and Szwejda [2006]. Briefly, 2.0 ml of the extract was mixed with 1.25 ml of deionized water and then 0.075 ml of 5% sodium nitrite ($NaNO_2$) solution, after 5 min of incubation, 0.15 ml of 10% $AlCl_3$ was added, and mixture was allowed to stand for 5 min. 0.5 ml of 1 M NaOH and water were added to final volume of 2.5 ml. The absorbance was measured at 510 nm (Lambda 25 spectrophotometer, PerkinElmer, Inc., Waltham, MA, USA). The total flavonoids content was expressed as catechin equivalent per g of fresh weight.

Statistical analysis. The results were statistically analyzed by ANOVA. The significance of differences was determined by Tukey's test at the significance level of $p = 0.05$. All the calculations were performed using STATISTICA® version 12.0 (Stat-Soft, Poland) and MS Excel®.

RESULTS AND DISCUSSION

Weight of fruits suitable for consumption. Of the initial fruit weight of 585 g, the most fruit that was suitable for consumption after 14 days of storage was determined in cold storage (Tab. 1). The weight of fruit suitable for consumption after 14 days of storage at temperatures 2–4°C and 6–8°C was similar. Significantly the smallest mass of high quality of fruit was found after storage at 18–20°C. A more favourable effect of storage at lower temperature was associated with slowed changes during postharvest fruit ripening, lower water loss, and slowed or inhibited growth and dispersion of harmful microorganisms [Irtwange 2006].

After 14 days of storage, the highest decline in the weight of fruit fit for consumption was observed in non-treated and non-bagged samples. Use of Xtend® bags as well as UV-C irradiation significantly reduced losses associated with fruit decay and mildewing. The greatest weight of fruit suitable for consumption was recorded after placing the product in Xtend® bags (B-UV600) and in flat polythene containers (no bags – NB-UV600), and exposition to UV-C radiation for 600 s. A statistically significant difference in the weight of fruit suitable for consumption was noticed between these combinations and the NB-UV0 combination. Pan et al. [2004] demonstrated that UV-C irradiation contributed to lower losses in strawberry fruit after 6-day storage at 20°C compared with losses in non-treated fruit. Also others authors reported that UV-C irradiation contributed to an extension of pineapple storage time [Manzocco et al. 2016]. After 28 days of storage at room temperature of 18-20°C, sweet cherry fruit completely decayed regardless of the method of postharvest handling. Storage at 2–4°C was associated with significantly higher weight of fruit fit for consumption. At this temperature, the highest weight of fruit suitable for consumption was determined for NB-UV600, also statistically similar to the NB-UV120 combination. At 6–8°C, the best postharvest fruit handling method was UV-C irradiation for 600 s, regardless of whether the fruit was bagged or not.

Number of fruit suitable for consumption. After 14 days of storage, among 55 fruit constituting the sample analysed, a significantly higher number of fruit fit for consumption was determined at the temperature of 2–4°C and 6–8°C than at 18–20°C (Tab. 2). At the temperature of 2–4°C, the greatest number of fruit fit for consumption was recorded for the combinations NB-UV120 and NB-UV600 whereas at 6–8°C and 18–20°C for the combination B-UV600.

After 28 days of storage, the higher number of fruits suitable for consumption was found at temperature of 2 –4°C. Regardless of the storage temperature, NB-UV120, NB-UV600 and B-UV600 were the most favourable postharvest handling methods, in terms of the number of fruit fit for consumption.

Nutrients content. Dry matter content, reducing sugars, ascorbic acid content, phenolics and flavonoids, determined directly after fruit harvest, are presented in Table 3. After 14 days of storage, fruit con-

Table 2. Number of fruits suitable for consumption

Postharvest handling (B)	Storage temperature (A)			Mean
	2–4°C	6–8°C	18–20°C	
After 14 days of storage				
B-UV0	46 ±1.53^{a}	46 ±2.00^{ab}	18 ±0.58^{b}	37 ±14.14^{b}
B-UV120	47 ±0.00^{a}	46 ±2.65^{ab}	19 ±2.31^{bc}	37 ±13.70^{b}
B-UV600	48 ±1.15^{a}	48 ±2.00^{b}	22 ±3.61^{c}	39 ±13.09^{b}
NB-UV0	47 ±0.58^{a}	43 ±2.00^{a}	13 ±4.73^{a}	34 ±16.37^{a}
NB-UV120	49 ±0.00^{a}	47 ±1.15^{b}	14 ±1.53^{a}	37 ±17.14^{b}
NB-UV600	49 ±0.58^{a}	48 ±0.58^{b}	19 ±1.53^{bc}	39 ±14.63^{b}
Mean	48 ±1.50^{B}	46 ±2.29^{B}	18 ±4.10^{A}	
ANOVA	*F*	*P*	$LSD_{0.05}$	
A	522.92	<0.001	3.5	
B	12.48	<0.001	2.4	
A × B	4.75	0.02	3.7	
After 28 days of storage				
B-UV0	26 ±6.81^{a}	25 ±2.08^{a}	–	26 ±4.51^{a}
B-UV120	34 ±1.53^{a}	21 ±5.86^{a}	–	27 ±8.08^{a}
B-UV600	33 ±3.42^{a}	35 ±3.61^{a}	–	34 ±3.35^{b}
NB-UV0	30 ±2.65^{a}	29 ±7.81^{a}	–	30 ±5.24^{ab}
NB-UV120	39 ±5.29^{a}	32 ±1.73^{a}	–	36 ±5.21^{b}
NB-UV600	36 ±6.08^{a}	34 ±5.51^{a}	–	35 ±5.27^{b}
Mean	33 ±5.89^{A}	29 ±6.68^{A}	–	
ANOVA	*F*	*P*	$LSD_{0.05}$	
A	6.04	>0.05	ns	
B	5.95	0.007	6.5	
A × B	2.77	>0.05	ns	

Abbreviations – see at section Materials and Methods
Each values are mean ±standard deviation, $n = 3$
Mean ±SD followed by different lowercase letters in columns and different uppercase letters in columns differ significantly at $p \leq 0.05$
F – F-distribution, *P* – probability, $LSD_{0.05}$ – least significant difference, ns – not significant

Table 3. Dry matter and the content of reducing sugars, ascorbic acid, phenolics and flavonoids at harvest

Dry matter (%)	Reducing sugars (g 100 g^{-1})	Ascorbic acid (mg 100 g^{-1})	Phenolics (mg 100 g^{-1})	Flavonoids (mg 100 g^{-1})
15.42 ±0.07	11.93 ±0.05	6.90 ±0.02	51.77 ±1.21	14.55 ±0.29

Table 4. Dry matter and the content of reducing sugars, ascorbic acid, phenolics and flavonoids at harvest after 14 days of fruit storage at room temperature

Postharvest handling (B)	Dry matter (%)	Reducing sugars (g 100 g^{-1})	Ascorbic acid (mg 100 g^{-1})	Phenolics (mg 100 g^{-1})	Flavonoids (mg 100 g^{-1})
B-UV0	15.90 ±1.00^{a}	11.16 ±0.24^{a}	6.53 ±0.23^{a}	37.00 ±3.69^{a}	10.37 ±2.48^{a}
B-UV120	16.50 ±0.22^{a}	11.70 ±0.33^{bc}	6.37 ±0.06^{a}	40.26 ±7.74^{a}	10.58 ±2.52^{a}
B-UV600	16.71 ±1.02^{a}	11.60 ±0.36^{b}	6.67 ±0.38^{a}	41.09 ±5.29^{a}	14.99 ±5.70^{b}
NB-UV0	16.48 ±0.72^{a}	11.24 ±0.36^{a}	6.53 ±0.21^{a}	30.00 ±8.74^{a}	11.78 ±0.51^{a}
NB-UV120	17.23 ±0.41^{a}	11.82 ±0.11^{bc}	6.47 ±0.21^{a}	41.99 ±7.67^{a}	11.02 ±0.71^{a}
NB-UV600	17.40 ±0.23^{a}	11.94 ±0.07^{c}	6.40 ±0.10^{a}	39.92 ±4.81^{a}	14.45 ±4.85^{b}
Mean	16.70 ±0.77	11.58 ±0.37	6.49 ±0.21	38.38 ±6.92	12.20 ±3.42
ANOVA					
F	2.78	8.51	0.52	3.52	7.45
P	>0.05	<0.001	>0.05	>0.05	0.04
$LSD_{0.05}$	ns	0.30	ns	ns	2.33

Abbreviations – see at section Materials and Methods
Each values are mean ±standard deviation, $n = 3$
Mean ±SD followed by different lowercase letters in columns and different uppercase letters in columns differ significantly at $p \leq 0.05$
F – F-distribution, *P* – probability, $LSD_{0.05}$ – least significant difference, ns – not significant

tained, on average, less reducing sugars, ascorbic acid, phenolics and flavonoids, and more dry matter than directly after harvest (Tables 3 and 4). UV-C-treated fruit contained significantly more reducing sugars than non-treated fruit. In the study performed by Pan et al. [2004] strawberries irradiated with UV-C and stored at 20°C contained less reducing sugars compared to the value prior to the treatment, the decline being higher compared with non-treated fruit. In the study of Charles et al. [2016] in ripe tomato fruit subjected to UV-C irradiation after harvest and stored for 10 and 15 days, one cultivar showed a significant increase, and two cultivars showed a significant decrease in sugar content in comparison with non-exposed products. The authors confirmed that for three varieties of tomato UV-C exposure had no effect on the change in the sugar content in the fruit.

After 14 days of storage at room temperature, insignificant changes in dry matter content, ascorbic acid content and phenolics were found (Tab. 4). However, the lower dry matter content was determined for bagged, non-treated fruit. UV-C irradiation combined with storage without bagging contributed to higher water losses due to transpiration, and increased dry matter content. The higher reducing sugar content was determined in fruit irradiated with UV-C for 600 s and stored without bagging, the lowest content being characteristic of non-treated fruit regardless of whether Xtend® bags were used or not. The greatest amount of ascorbic acid and phenolics was found in fruit stored in Xtend® bags and irradiated with UV-C for 600 s. The higher total phenolic content was recorded for non-bagged fruit treated with UV-C for 120 s. The higher content of flavonoids was characteristic for sweet cherry fruit irradiated with UV-C for 600 s, regardless of whether Xtend® bags were used or not.

After 28 days of storage, dry matter content and reducing sugars of fruit stored at 2–4°C and 6–8°C didn't differ significantly (Tab. 5). Regardless of the packaging method, extension of UV-C exposure time from 120 to 600 s increased water losses in tissues and contributed to an increase in dry matter content. The highest dry matter content was recorded in fruit exposed to UV-C for 600 s and stored without bagging. In contrast, postharvest fruit treatment caused insignificant changes in reducing sugar content. However, a tendency was observed for reducing sugars content to increase as the UV-C irradiation dose increased.

Table 5. Dry matter content and reducing sugars after 28 days of fruit storage

Postharvest handling (B)	Storage temperature (A)		Mean
	2–4°C	6–8°C	
	Dry matter (%)		
B-UV0*	17.10 ±0.87[a]	17.05 ±0.72[a]	17.08 ±0.71[a]
B-UV120	16.97 ±0.04[a]	17.42 ±0.09[a]	17.20 ±0.26[ab]
B-UV600	17.74 ±0.29[a]	17.92 ±0.15[a]	17.83 ±0.23[b]
NB-UV0	17.74 ±0.72[a]	17.67 ±0.57[a]	17.71 ±0.58[ab]
NB-UV120	17.83 ±0.44[a]	17.81 ±0.63[a]	17.82 ±0.49[b]
NB-UV600	18.64 ±0.32[a]	18.40 ±0.49[a]	18.52 ±0.39[c]
Mean	17.67 ±0.72[A]	17.71 ±0.60[A]	
ANOVA	*F*	*P*	$LSD_{0.05}$
A	0.06	>0.05	Ns
B	8.01	<0.001	0.67
A × B	0.40	>0.05	Ns
	Reducing sugars (g 100 g^{-1})		
B-UV0	11.72 ±0.28[a]	11.85 ±0.14[a]	11.78 ±0.21[a]
B-UV120	11.71 ±0.11[a]	12.11 ±0.37[a]	11.91 ±0.32[a]
B-UV600	12.10 ±0.16[a]	12.13 ±0.34[a]	12.12 ±0.24[a]
NB-UV0	12.04 ±0.35[a]	11.62 ±0.36[a]	11.83 ±0.39[a]
NB-UV120	12.21 ±0.43[a]	11.93 ±0.19[a]	12.07 ±0.33[a]
NB-UV600	12.33 ±0.12[a]	12.25 ±0.31[a]	12.29 ±0.22[a]
Mean	12.02 ±0.33[A]	11.98 ±0.33[A]	
ANOVA	*F*	*P*	$LSD_{0.05}$
A	0.21	>0.05	ns
B	3.11	>0.05	ns
A × B	2.63	>0.05	ns

Abbreviations – see at section Materials and Methods
Each values are mean ±standard deviation, $n = 3$
Mean ±SD followed by different lowercase letters in columns and different uppercase letters in columns differ significantly at $p \leq 0.05$
F – F-distribution, *P* – probability, $LSD_{0.05}$ – least significant difference, ns – not significant

Contrary results were reported by Erkan et al. [2001], who found significantly less amount of reducing sugars in pumpkin fruit exposed to UV-C for 60 s and 600 s and then stored at 5°C or 10°C for 18 days, compared with non-treated fruit. Obtained results of own research as well as research of the following authors [Erkan et al. 2001, Pan et al. 2004, Charles et al. 2016] suggest that the effect of UV-C irradiation on the sugar content of fruits is ambiguous and may depend on the species and even plant variety, UV-C exposure time and the length of storage of the fruit after exposure.

Postharvest treatment and temperature of storage did not affect ascorbic acid content but they significantly influenced the total content of phenolics and flavonoids (Tab. 6). Also Artés-Hernández et al. [2010], found no significant changes in the watermelon fruit content of vitamin C as affected by exposure to UV-C whereas Chaudhary et al. [2015], found no

Table 6. Content of oxidative components after 28 days of fruit storage

Postharvest handling (B)	Storage temperature (A)		Mean
	2–4°C	6–8°C	
	Ascorbic acid (mg 100 g^{-1})		
B-UV0	6.63 ±0.40^{a}	6.53 ±0.06^{a}	6.58 ±0.26^{a}
B-UV120	6.47 ±0.21^{a}	6.30 ±0.10^{a}	6.38 ±0.17^{a}
B-UV600	6.50 ±0.00^{a}	6.80 ±0.26^{a}	6.65 ±0.23^{a}
NB-UV0	6.83 ±0.15^{a}	6.50 ±0.10^{a}	6.67 ±0.22^{a}
NB-UV120	6.43 ±0.15^{a}	6.47 ±0.21^{a}	6.45 ±0.16^{a}
NB-UV600	6.63 ±0.23^{a}	6.57 ±0.15^{a}	6.60 ±0.18^{a}
Mean	6.58 ±0.24^{A}	6.53 ±0.21^{A}	
ANOVA	*F*	*P*	$LSD_{0.05}$
A	2.04	>0.05	ns
B	1.83	>0.05	ns
A × B	1.59	>0.05	ns
	Phenolics (mg 100 g^{-1})		
B-UV0	32.31 ±3.16^{a}	38.66 ±4.19^{a}	35.49 ±4.81^{a}
B-UV120	30.27 ±6.50^{a}	39.98 ±1.63^{a}	35.13 ±6.80^{a}
B-UV600	33.30 ±8.37^{a}	48.71 ±8.51^{b}	41.00 ±11.32^{ab}
NB-UV0	43.34 ±3.12^{b}	42.20 ±6.81^{ab}	42.77 ±4.78^{b}
NB-UV120	44.90 ±0.67^{b}	56.97 ±7.41^{c}	50.94 ±8.11^{c}
NB-UV600	45.77 ±4.67^{b}	47.47 ±3.32^{b}	46.62 ±3.74^{bc}
Mean	38.32 ±7.89^{A}	45.67 ±8.08^{B}	
ANOVA	*F*	*P*	$LSD_{0.05}$
A	36.98	<0.001	3.40
B	10.02	<0.001	7.17
A × B	3.91	0.04	7.12
	Flavonoids (mg 100 g^{-1})		
B-UV0	10.85 ±0.25^{a}	11.72 ±3.24^{a}	11.29 ±2.11^{a}
B-UV120	10.09 ±3.10^{a}	13.51 ±0.89^{a}	11.80 ±2.77^{a}
B-UV600	11.02 ±0.83^{a}	14.35 ±2.81^{a}	12.69 ±2.60^{ab}
NB-UV0	10.49 ±1.84^{a}	12.45 ±3.23^{a}	11.47 ±2.59^{a}
NB-UV120	11.87 ±1.59^{a}	17.63 ±1.42^{a}	14.75 ±3.43^{bc}
NB-UV600	15.72 ±0.48^{a}	16.89 ±1.02^{a}	16.30 ±0.96^{c}
Mean	11.67 ±2.39^{A}	14.43 ±2.98^{B}	
ANOVA	*F*	*P*	$LSD_{0.05}$
A	23.13	<0.001	1.61
B	7.12	0.008	2.79
A × B	1.07	>0.05	ns

Abbreviations – see at section Materials and Methods
Each values are mean ±standard deviation, $n = 3$
Mean ±SD followed by different lowercase letters in columns and different uppercase letters in columns differ significantly at $p \leq 0.05$
F – F-distribution, *P* – probability, $LSD_{0.05}$ – least significant difference, ns – not significant

effect of modified atmosphere on ascorbic acid content in grapefruit. Phenolic compounds are secondary metabolites which exhibit anti-oxidative activity, and are important anti-oxidants in human nutrition [Park and Kim 2014]. In the present study, fruit stored at 6–8°C contained significantly more phenolic compounds compared with the ones stored at 2–4°C.

At 2–4°C fruit packed in Xtend® bags contained significantly less phenolics than non-bagged fruit regardless of whether they were irradiated with UV-C or not. At 6–8°C, non-bagged fruit exposed to UV-C for 120 s contained the higher amount of phenolics, their content increased by 10% when compared to the content noted directly after harvest. Fruits from the NB-UV120 combination contained significantly the most phenols, whereas from the combination of NB-UV600 and B-UV600 they contained significantly more than from the combination of B-UV0 and B-UV120. It was observed that extending the exposure time of fruits not packed in Xtend® bags to UV-C radiation to 600 s caused a significant decrease of phenolics content in relation to the NB-UV120 object. This phenomenon was not observed in the case of fruit packed in Xtend® bags, as well as in fruit stored at a lower temperature (2–4°C) and irradiated also for 600 s. It is believed that the decrease in phenolics content on the NB-UV600 object may have been caused by the highest intensity of UV-C radiation reaching the fruit surface and a higher storage temperature. Most researchers [Wang et al. 2009, Martinez-Hernandez et al. 2011, Michailidis et al. 2019, Abdipour et al. 2020] indicates an increase in the content of phenolics and other anti-oxidants in edible parts of plants exposed to UV-C radiation. However, there are studies which show a decrease in the content of these compounds in plants or a lack of reaction to UV-C exposure. Artés-Hernández et al. [2009] observed a decrease in the phenolic content of spinach leaves after they were exposed to 4.54, 7.94 and 11.35 kJ UV-C·m^{-2}, regardless of storage temperature. After 6 days of storing broccoli exposed to 10 kJ UV-C·m^{-2}, Costa et al. [2006], found an increase in phenolic content which was followed by a decline after storage termination, compared with the control. Cisneros-Zevallos [2003] believes that UV-C radiation causes abiotic stress which, according to Martínez-Hernández et al. [2011], may lead to an increase in phenolic compounds following irradiation. In turn, Artés-Hernández et al. [2010] found no effect of exposure to UV-C on phenolic content in watermelon fruit. The authors reported that a decrease in the content of these compounds in watermelon cut into cubes progressed during storage whether the cubes had been exposed to UV-C (at various doses) or not. Also Perkins-Veazie et al. [2008] did not show a clear UV-C effect in total phenolic content in blueberries after 7 days at 5°C plus 2 days at 20°C. Consequently, the effects of UV-C on phenolic content have not been yet completely elucidated and more research is needed.

As the dose of UV-C radiation increased, the total content of flavonoids increased as well. Higher content of flavonoids were found in fruit stored in containers which were exposed to UV-C without a physical barrier created by Xtend® bags. By contrast, Chaudhary et al. [2015] noticed that grapefruit stored in bags under the conditions of modified atmosphere had increased flavonoid contents compared with non-bagged fruit. In the present study, regardless of the temperature during storage, the highest flavonoid content was determined in fruit exposed to 1.03 and 5.16 kJ·m^{-2} UV-C. An increase in the highbush blueberry (*Vaccinium corymbosum* L.) fruit content of flavonoids following exposure to UV-C was also reported by Wang et al. [2009]. The mechanism of action of UV-C radiation is not recognized. Liu et al. [2012] hypothesize that very high intensity of UV-C radiation may be harmful to cell membranes, leading to a decrease in the content of compounds with antioxidant properties, including ascorbic acid, causing its oxidation.

UV-C irradiation can be successfully used to improve fruit storages. This method should also be used in time-consuming transport of soft fruits over long distances, allowing them to reach their destination without storage damage. Besides, UV-C irradiation can bring many benefits to food producers: it leaves no residue in the treated food, it is cheap and easy to use, effective in removing most microorganisms.

CONCLUSIONS

Storage in Xtend® bags and irradiation for 600 seconds gave the best results in prolonging the shelf life of cherry fruit at 6–8°C and at room temperature.

At 2–4°C a much slower loss of fruit shelf life was observed, therefore the effect of Xtend® bags and UV-C radiation was less noticeable in the initial storage period. The effect of irradiation was revealed after storage lasting 4 weeks. Furthermore fruit placed in Xtend® bags and in flat polyethylene containers and irradiated by UV-C for 600 s contained the higher amount of flavonoids. Their content was similar to the amount determined in fruits obtained immediately after harvest. The content of ascorbic acid regardless of the postharvest treatment and storage conditions did not change significantly in relation to the initial content, both after 14 and after 28 days of fruit storage.

More preferably, the contents of phenols and flavonoids in sweet cherry fruit were influenced by loose storage in open polyethylene containers. Significantly higher content of these compounds was also determined after fruit storage at 6–8°C, than at 2–4°C.

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