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THE EFFECT OF SHORT-TERM STORAGE AND THE HOT WATER TREATMENT OF FRESH-CUT PEPPER FRUIT CV. 'BLONDY F₁' AND 'YECLA F₁' ON THE CONTENT OF BIOACTIVE COMPOUNDS AND ANTIOXIDANT PROPERTIES

Justyna I. SZWEJDA-GRZYBOWSKA*, Ryszard KOSSON, Maria GRZEGORZEWSKA

Research Institute of Horticulture
Konstytucji 3 Maja 1/3, 96-100 Skierniewice, Poland

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ABSTRACT

The aim of the experiment was to determine the changes in the contents of bioactive compounds and antioxidant/antiradical activity in fresh-cut fruits of sweet pepper cv. 'Blondy F₁' and 'Yecla F₁', depending on the postharvest treatment. Treatment with hot water and short-term storage decreased the content of bioactive compounds and antioxidant/antiradical activity of fruit peppers. The treatment with water at 55 °C for 12 sec. of fresh-cut fruits caused lower losses in content of bioactive compounds and antioxidant/antiradical activities than the treatment with water at 45 °C for 10 min. There was a significant correlation between the content of total polyphenols and antioxidant and antiradical activity of pepper fruits depending on the cultivar and the experimental season.

Key words: pepper, antioxidant activity, antiradical activity, short-term storage, minimal processing

INTRODUCTION

There is a growing interest among consumers for minimally processed fruit and vegetables – partially or completely prepared for immediate consumption. Technology of minimal processing allows the use of fruits and vegetables in the condition most similar to fresh. One of the important problems limiting the sale of minimally processed vegetables is their poor durability. Due to very limited processing, the biochemical and microbiological processes that occur may lead to disqualification of the product within only a few days of storage because of the sensory changes. In many species of fresh vegetables, including peppers, a decrease in the content of bioactive compounds was observed shortly after fruit harvesting, especially when stored at room temperature (Favell 1998). Another factor contributing to the occurrence of adverse biochemical changes is shredding. It can lead to the destruction of the natural skin barriers, and allows faster

multiplication of microorganisms, as well as facilitates the contact of released enzymes with their substrates and accelerates cell respiration (Yildiz 1994). It may also increase the production of ethylene (Varoquaux & Wiley 1994). In vegetables, a catalyzed oxidation of unsaturated fatty acids by enzymes may occur, leading to the formation of aldehydes and ketones having a significant impact on the flavor of product. In addition, the enzymatic browning reactions, decomposition of chlorophyll and loss of firmness are frequent (Varoquaux & Wiley 1994). The assessment of microbiological quality of minimally processed vegetables present in our market was the subject of studies of Leszczyńska-Fik and Fik (2003), and Radziejewska-Kubzdela et al. (2007). The above authors did not find the pathogenic bacteria belonging to *Salmonella* sp. or *Listeria* sp. in the processed products, but bacteria of the group *Coli* were present. Leszczyńska-Fik and Fik 2003 suggested that they cannot be indifferent to the health of consumers,

*Corresponding authors:
e-mail: justyna.grzybowska@inhort.pl

especially for people with reduced immunity. In order to improve the storage stability of vegetables, treatment with high temperature (about 60 °C) was studied. It has been found that this treatment has the influence on lowering rate of respiration, reducing the production of ethylene, delaying ripening, and the reduction of contamination by pathogens of several vegetable species (Lurie 1998; Fallik et al. 1999; Ferguson et al. 2000). Lurie (1998) and Saltveit (1998) found that high temperature favors the formation of Heat Shock Proteins that may contribute to increase of resistance to stresses during storage caused by microorganism infections and physiological disorders (Vlachonasios et al. 2001). Dipping whole pepper fruits for 3 minutes in hot water of 50 °C reduced their damage by the fungi *Botrytis cinerea* and *Alternaria alternata* during storage. Fallik et al. (1999; 2004) found that the use of hot water to gently brushing pepper fruit before storage led to increase fruit durability.

The use of new technology for improving the storage stability of sliced vegetables, should contribute to an increase in their range in the market, reducing losses and increasing the consumption of fresh fruit and vegetables.

There is still limited information in the literature about the influence of postharvest treatment on the contents of bioactive compounds, antioxidant and antiradical activity of sweet pepper fruits. Therefore, the aim of the study was to evaluate some consequences of pre-storage hot water treatments of stripped sweet pepper fruit on the content of bioactive compounds and antioxidant activities.

MATERIALS AND METHODS

Two cultivars of sweet pepper (*Capsicum annuum*) cvs Blondy F₁ (white fruit) and 'Yecla F₁' (red fruit) were used for the experiment conducted in 2011–2013. The fruits in the stage of consumption ripeness were bought in the company "Agropaprix" in Przysławowice Duże – Kolonia. Immediately after their arrival, they had been washed in water, dried in a stream of air by fans, and then cut into longitudinal strips with a width of 0.5–1.0 cm. One part of each strip was immediately transferred

to 5 °C (Control II), the second was treated with hot water at 45 °C for 10 min. and the third with water at 55 °C for 12 sec. followed by drying in a stream of air by fan. All strips were packed in PE bags (20 × 15 cm) with perforations (6 holes 0.04 cm diameter) and transferred for storage at the temperature 5 °C for 4 days. Control I was immediately analyzed for chemical properties. The experiment was set in 4 replicates with 200 g of fruit in each bag.

The following chemical compounds were determined:

- the content of total polyphenols by the spectrophotometric Folin-Ciocalteu method using a spectrophotometer UviLine 9400 at wave length 750 nm according to Sluis et al. (2002) and using catechin as a standard;
- the total content of flavonoids by the spectrophotometric method using a spectrophotometer UviLine 9400 at wave length 510 nm according to Zhishen et al. (1999) and Eberhardt et al. (2000) and using catechin as a standard;
- the total content of carotenoids by the spectrophotometric method using a spectrophotometer UviLine 9400 at wave length 451 nm according to Davis (1965) and Umiel and Gabelman (1971);
- the content of ascorbic acid using 2,6-dichlorophenylindophenol titrimetric method according to PN-A-04019(1998).
- the antioxidant activity (AOA) by β -carotene bleaching method based on coupled oxidation of β -carotene and linoleic acid according to Emmons et al. (1999) and the antiradical activity (ARA) by 2,2-diphenyl-1-picrylhydrazyl (DPPH•) free radical scavenging assay according to Brand-Williams et al. (1995) and Sánchez -Moreno et al. (2002).

Statistical calculations were performed using STATISTICA v. 10 (StatSoft 2011) as one-way analysis of variance separately for seasons and cultivars. The significant differences between means were determined at $p = 0.05$ by Tukey's test. The results are expressed as the mean of three replicates ($n = 3$). The correlation coefficient (r) was used to determine the relationship between polyphenol content and antioxidant and antiradical activity of stripped pepper fruit.

Table 1. The influence of hot water treatment and short-term storage on the content of bioactive compounds in sweet pepper fruits.

Cultivar	Treatment temperature and storage period	Total polyphenols (mg·kg ⁻¹ f.m.)	% to control I	Total flavonoids (mg·kg ⁻¹ f.m.)	% to control I	Total carotenoids (mg·kg ⁻¹ f.m.)	% to control I	Ascorbic acid (mg·kg ⁻¹ f.m.)	% to control I
Season 2011									
'Blondy F ₁ '	Control I (0 days)	655±7 a		73±1 a		1.0±0.1 a		123±11 a	
	Control II (4 days)	606±4 b	7	73±1 ab		0.9±0.1 a		98±93 c	21
	45 °C 10 min. (4 days)	551±13 c	16	57±1 c	22	0.8±0.1 a		102±2 c	17
	55 °C 12 sec. (4 days)	562±10 b	14	66±1 b	10	1.2±0.0 a		110±17 b	11
'Yecla F ₁ '	Control I (0 days)	957±7 a		118±1 a		104.4±4.6 b		154±11 a	
	Control II (4 days)	767±13 b	20	83±2 b	30	112.1±5.3 ab		142±3 b	
	45 °C 10 min. (4 days)	607±17 d	37	68±1 d	42	104.5±3.8 b		148±4 ab	
	55 °C 12 sec. (4 days)	674±13 c	30	76±1 c	36	114.1±3.9 a		149±0 a	
Season 2012									
'Blondy F ₁ '	Control I (0 days)	561±10 a		77±2 a		3.7±0.3 a		112±8 a	
	Control II (4 days)	529±8 a		81±4 a		1.7±0.2 a		102±5 b	9
	45 °C 10 min. (4 days)	421±3 b	25	64±1 b	17	1.2±0.2 a		98±1 b	13
	55 °C 12 sec. (4 days)	450±6 b	20	74±1 a	20	1.3±0.2 a		98±5 b	12
'Yecla F ₁ '	Control I (0 days)	584±10 a		99±3 a		48.1±1.6 a		162±5 a	
	Control II (4 days)	563±8 ab		95±4 a		51.0±1.9 a	23	158±2 a	
	45 °C 10 min. (4 days)	520±7 c	11	79±2 c	20	35.1±0.7 b		147±6 b	7
	55 °C 12 sec. (4 days)	524±6 b	10	84±1 b	15	51.0±1.3 a		146±5 b	7
Season 2013									
'Blondy F ₁ '	Control I (0 days)	801±2 a		108±2 a		3.4±2.1 a		110±8 a	
	Control II (4 days)	787±3 ab		103±1 ab		2.7±1.1 a		101±8 b	8
	45 °C 10 min. (4 days)	693±19 c	13	93±2 b	13	1.7±2.9 a		85±12 d	22
	55 °C 12 sec. (4 days)	752±11 b	6	99±2 b	8	2.4±2.2 a		94±33 c	15
'Yecla F ₁ '	Control I (0 days)	1135±15 a		153±2 a		94.9±0.3 b		203±17 a	
	Control II (4 days)	985±10 b	13	150±1 ab		113.5±0.1 a	20	204±33 a	
	45 °C 10 min. (4 days)	950±11 b	16	136±2 c	11	82.8±0.2 c	13	189±54 b	7
	55 °C 12 sec. (4 days)	977±26 b	14	145±1 b	5	97.3±0.2 b		193±33 b	5

RESULTS AND DISCUSSION

Fresh fruit samples of two cultivars of sweet pepper differed at the start of experiment (Control I) for nearly all the studied traits, what was the result of genetic differences. The range of differences depended on the year. The values were higher in 2011 and 2013 than in 2012 (Table 1, 2). The greatest differences were in carotenoid content (from about 17 to 100x more in 'Yecla F₁' than 'Blondy F₁'). Also, the growth season influenced values of all parameters at the start of experiment. It was the reason that statistical analyses were conducted for cultivars and seasons separately.

For most of the analyzed traits, the highest values were obtained in 2013. Thermal conditions for

the growth of peppers during the growing season 2013 were appropriate for thermophilic plants, with an average temperature above 18 °C, from June to the end of August. In addition, a large number of sunshine hours compared to other years was noted. It is well known that not only the indigenous plant traits but also external factors, including weather conditions (temperature, rainfall, hours of sunshine) decide on the scope and shape of these changes (Buczowska 1991; Gaye et al. 1992; Korzeniewska & Niemirowicz-Szczyt 1997).

A higher content of bioactive compounds, as well as antioxidant and antiradical activity characterized the fruit of pepper 'Yecla F₁' than the fruits of 'Blondy F₁', regardless of the examined factors (Table 1, 2).

Table 2. The influence of hot water treatment and short-term storage on the antioxidant (AOA) and antiradical activity (ARA) in pepper fruits (2011–2013)

Cultivar	Treatment temperature and (storage period)	AOA (%)	% to Control I	ARA (%)	% to Control I
Season 2011					
'Blondy F ₁ '	Control I (0 days)	32.3±2.4 a		74.1±2.0 a	
	Control II (4 days)	27.2±2.8 a		64.2±1.2 b	13
	45 °C 10 min. (4 days)	16.6±2.2 b	49	49.5±1.1 c	49
	55 °C 12 sec. (4 days)	19.0±1.7 b	41	67.7±5.3 ab	
'Yecla F ₁ '	Control I (0 days)	61.4±0.7 a		77.8±2.0 a	
	Control II (4 days)	45.3±1.9 b	26	55.6±1.2 b	29
	45 °C 10 min. (4 days)	33.1±0.7 d	46	38.9±2.9 c	50
	55 °C 12 sec. (4 days)	39.6±0.3 c	36	49.3±2.5 b	38
Season 2012					
'Blondy F ₁ '	Control I (0 days)	41.1±1.6 a		49.9±1.4 a	
	Control II (4 days)	33.0±1.0 b	20	38.8±1.0 b	22
	45 °C 10 min. (4 days)	16.1±1.1 d	61	31.7±1.5 c	36
	55 °C 12 sec. (4 days)	22.8±1.4 c	45	35.4±0.6 bc	29
'Yecla F ₁ '	Control I (0 days)	43.7±1.7 a		53.8±3.1 a	
	Control II (4 days)	28.6±1.5 b	35	44.7±1.4 b	17
	45 °C 10 min. (4 days)	17.0±0.8 c	61	37.6±1.0 b	30
	55 °C 12 sec. (4 days)	25.4±1.0 b	58	39.1±1.0 b	27
Season 2013					
'Blondy F ₁ '	Control I (0 days)	36.8±0.4 a		76.4±2.4 a	
	Control II (4 days)	30.1±1.0 b	18	64.7±2.7 b	15
	45 °C 10 min. (4 days)	23.4±1.1 c	36	56.2±0.3 c	26
	55 °C 12 sec. (4 days)	25.1±0.7 b	32	64.6±2.0 b	15
'Yecla F ₁ '	Control I (0 days)	42.1±1.1 a		90.2±1.5 a	
	Control II (4 days)	37.7±0.8 ab		82.5±2.1 b	9
	45 °C 10 min. (4 days)	28.4±0.8 c	33	84.7±0.3 ab	
	55 °C 12 sec. (4 days)	32.1±1.1 b	24	87.4±0.5 ab	

Note: Means in the column for each cultivar and year separately marked with the same letter are not significantly different according to Tukey's test ($p = 0.05$).

According to Häkkinen & Törrönen (2000); Howard et al. (2000); Wang and Lin (2000); Borowska (2003); Perucka et al. (2004); Ozgur et al. (2011), the composition and the content of bioactive compounds in the pepper fruit depend on the cultivar and maturity stage and are higher in the fully colored fruits. Also, the antioxidant and antiradical activities depend on the cultivar (Ghasemnezhad et al. 2011; Medina-Juárez et al. 2012; Campos et al. 2013; Ornelas-Paz et al. 2013; Shaha et al. 2013; Loizzo et al. 2015).

In our study, the storage of stripped pepper fruit for 4 days at 5 °C caused a decrease in the content of polyphenols by 2–7% in 'Blondy F₁' and 11–20% in 'Yecla F₁', depending on the year. Total flavonoids and carotenoids contents were not affected by the storage. Ascorbic acid contents decreased in the result of storage by 8 to 21% in 'Blondy F₁' but not in 'Yecla F₁'.

The treatment with water at 45 °C for 10 min. before storage decreased the content of polyphenols by 12–25% in 'Blondy F₁' and by 11–37% in 'Yecla F₁'. Also, the total flavonoids content decreased by this treatment by 13–22% in 'Blondy F₁' and 11–42% in 'Yecla F₁'. Carotenoids content was not affected in 'Blondy F₁' and in 'Yecla F₁' only in 2012 and 2013 by 13 and 23%. Ascorbic acid contents decreased in 'Blondy F₁' by 13–22% and in 'Yecla F₁' only in 2012 and 2013 by 7%.

The treatment with water at 55 °C for 12 sec. before storage decreased the total polyphenols contents of 'Blondy F₁' by 6–20% and in 'Yecla F₁' by 10–30%. Total flavonoids in 'Blondy F₁' decreased by 8–10% only in 2011 and 2013, and in 'Yecla F₁' by 5–36%. The carotenoid content was not affected

and the ascorbic acid content decreased by 11–15% in 'Blondy F₁' and by 5–7% in 'Yecla F₁' in 2012 and 2013.

In our study, antioxidant and antiradical activity of pepper fruit strips was affected by the 4-day storage at 5 °C. AOA in 'Blondy F₁' was lower in 2012 and 2013 by 20 and 18%, and in 'Yecla F₁' by 26–35%. ARA was lower by 13–22% in 'Blondy F₁' and by 9–29% in 'Yecla F₁'. The treatment with water at 45 °C for 10 min decreased AOA by 36–61% in 'Blondy F₁' and by 30–50% in 'Yecla F₁' (only in 2011 and 2012). The treatment with water at 55 °C for 12 sec. decreased AOA by 32–45% in 'Blondy F₁' and by 24–58% in 'Yecla F₁'. ARA was not affected in 'Blondy F₁' in 2011 and in 2012 and 2013 decreased by 29 and 15%. In 'Yecla F₁', ARA was affected in 2011 and 2012 by 28 and 37% respectively (Table 1, 2).

Comparing the two treatments with hot water indicates that in almost every case, the greater reduction of contents and activities was recorded using water at 45 °C for 10 min than at 56 °C for 12 sec.

There are several papers concerning short-storage of fresh cut vegetables. Grzegorzewska (2014) found a slight decrease in storage quality in the fresh cut peppers, stored for 4 days at 5 °C, both treated and untreated with hot water but its commercial value was still high. The best quality was observed when the fresh cut pepper fruit were treated with water at 55 °C for 12 sec. in comparison with treatments at 45 °C for 10 min, 50 °C for 5 min. and 53 °C for 3 min. This suggests that slight decrease in the quality of storage could have an impact on reducing the content of bioactive compounds and antioxidant activity.

Table 3. The linear correlation coefficient (r) characterizing the relationship between the content of total polyphenols (mg·kg⁻¹ f.m.) and antioxidant and antiradical activity (%) of pepper fruits treated with hot water and stored for 4 days (2011–2013)

Cultivar	polyphenols/AOA correlation coefficient			polyphenols/ARA correlation coefficient		
	Season					
	2011	2012	2013	2011	2012	2013
‘Blondy F ₁ ’	0.592**	0.937***	0.819***	0.866***	0.817***	0.828***
‘Yecla F ₁ ’	0.983***	0.954***	0.781***	0.979***	0.862***	0.614**

***p ≤ 0.001, **p ≤ 0.01

Table 4. The linear correlation coefficient (r) characterizing the influence of the short-term storage on the relationship between the content of total polyphenols ($\text{mg} \cdot \text{kg}^{-1}$ f.m.) and antioxidant and antiradical activity (%) of pepper fruits (2011–2013)

Storage (days)	polyphenols/AOA correlation coefficient			polyphenols/ARA correlation coefficient		
	Season					
	2011	2012	2013	2011	2012	2013
0	0.978***	0.142	0.881***	0.680**	0.148	0.918***
4	0.789***	0.634**	0.789***	-0.039	0.850***	0.940***

*** $p \leq 0.001$, ** $p \leq 0.01$

Table 5. The linear correlation coefficient (r) characterizing the influence of hot water treatment on the relationship between the content of total polyphenols ($\text{mg} \cdot \text{kg}^{-1}$ f.m.) and antioxidant and antiradical activity (%) of pepper fruits (2011–2013)

Temp. treatment (°C)	polyphenols/AOA correlation coefficient			polyphenols/ARA correlation coefficient		
	Season					
	2011	2012	2013	2011	2012	2013
Control I	0.968***	0.452	0.797***	0.367	0.702**	0.844***
45	0.963***	0.820***	0.711***	0.709**	0.878***	0.897***
55	0.914***	0.867***	0.721***	0.460	0.849***	0.880***

*** $p \leq 0.001$, ** $p \leq 0.01$

Barbagallo et al. (2012) stated that during the storage of fresh cut yellow and red fruit of pepper for fourteen days at 4 °C the content of ascorbic acid was reduced, but the polyphenols content increased. On the other hand, Michalczyk and Macura (2008) in their study during the storage of lamb's lettuce, arugula and iceberg lettuce for 9 days at 0 and 6 °C observed a decrease in the content of polyphenols, carotenoids and ascorbic acid.

A significant correlation was found between the content of total polyphenols and antioxidant and antiradical activity of the two cultivars of sweet peppers, regardless of the temperature treatment with hot water and period of short-term storage, in each experimental season (Table 3). A positive correlation between polyphenol content and AOA and ARA activity in both pepper cultivars have also been found, depending on the period of short-term storage and the temperature treatment with hot water, the differences were significant, although not in every year (Table 4, 5).

CONCLUSIONS

1. The storage of fresh cut sweet pepper fruit 'Blondy F₁' and 'Yecla F₁' for 4 days at 5 °C diminished the contents of bioactive substances and antioxidant and antiradical activity, but the reduction was not significant in each of the seasons.
2. The treatment with hot water (45 °C for 10 min., 55 °C for 12 sec.) preceding the short-term storage of fresh cut pepper fruit 'Blondy F₁' and 'Yecla F₁' had a significant impact on reducing the content of bioactive compounds and antioxidant properties. Treatment with water at 55 °C for 12 sec. caused lower losses in content of bioactive compounds and antioxidant and antiradical activity than the treatment with water at 45 °C for 10 min.
3. The antioxidant and antiradical activity was significantly dependent on the content of total polyphenols in fruit of pepper 'Blondy F₁' and

‘Yecla F₁’ after the treatment with water (45 °C – 10 min. or 55 °C – 12 sec.) and the short term storage, in each experimental season.

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