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NUTRIENTS CONTENT AND TEXTURE CHANGES AS EFFECT OF HARVEST TIME, POSTHARVEST TREATMENTS AND STORAGE CONDITION OF CARROT

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ABSTRACT

The purpose of this study was to examine the effect of harvest time (November or January) and postharvest treatments (hot water (50°C), H_2O_2 (1%), NaOCl (175 ppm)) and nonwashed-control of carrots (*Daucus carrota* L. cv. 'Maestro F_1') on the changes in nutrient composition and texture under different storage conditions (S-1: 0°C, 98% RH; S-2: 0–2°C, 85–92% RH). Weight loss and quality changes in carrot roots were evaluated after 120 and 180 days of storage period (SP). After SP weight loss ranged from 3.20% (carrots from the first harvest in S-1 with H_2O_2 treatment) to 34.51% (carrots from the first harvest in S-2 with hot water treatment). Dry matter (DM) content in carrot roots varied in dependence of the harvest time (9.57–12.22%) and increased after the SP exept in carrot from first harvest with hot water and H_2O_2 treatments in S-1. Total sugar content (TSC) increased after SP, more in S-2 cooling room. Vitamin C content in carrot roots decreased more in S-2 (20.7–52.3%) in comparison to S-1 storage conditions (2.0–18.2%). The hardness and flexibility of carrot roots increased after SP for all treatments. Prestorage washing treatments (H_2O_2 or NaOCl) and storage in S-1 storage regime at temperature (0°C) with a high relative humidity 98% maintained quality of carrot root.

Key words: *Daucus carota*, prestorage treatments, dry matter, total sugar, vitamin C, hardness, flexibility

INTRODUCTION

Carrot (*Daucus carota* L.) is the most important root vegetable crop worldwide and is cultivated both for the fresh market and processing industry. Carrots are rich in bioactive compounds like carotenoids and dietary fibres, with appreciable levels of several other functional components with significant health-promoting properties [Sharma et al. 2012]. Carrot and other root vegetables have many positive properties that gained them an important role in the human diet: they are relatively cheap, can be locally produced worldwide and stored for a long period [Rydenheim 2008]. In the carrot pro-

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duction areas of Serbia (South Banat region), the most common storage method that farmers employ is to leave the mature roots un-harvested in the field during the winter period and to harvest roots only when the product is about to be sold. This storage method can result in crop losses of up to 25–30%, with damage mostly occurring when the soil freezes [Ilić et al. 2013]. The carrot quality characteristics are influenced by both biotic and abiotic parameters, and after harvest, the critical operations are handling, postharvest treatment and storage conditions [Seljåsen et al. 2013].

Storage temperature at 0°C is essential to minimize decay and sprouting during storage. High relative humidity (98 to 100% RH) is required to prevent desiccation and loss of crispness. Under this condition, mature topped carrots can be stored for 7 to 9 months [Luo et al. 2004]. The decision to wash carrots before storage, or immediately before sale during the winter months is usually based on a farm's washing facilities and available labor and the storage conditions appled by carrot growers in Serbia quite often deviate from the optimal values in terms of both temperature and relative humidity [Ilić and Šunić 2015]. Combined effect of pre- and postharvest treatments has significant effect on maintaining postharvest quality and extension of carrot shelf life [Seyoum et al. 2011]. Effects of prestorage treatments implying washing with addition of diverse agents on root vegetable shelf life were extensively investigated. Treatments in calcium chloride (3%), hydrogen peroxide (0.5%) or hot water (3 min at 50°C) were proven to be more effective compared to the washing in tap water in maintaining the quality and shelf life of the carrot root at room temperature [Isaac and Maalekuu 2013]. Carrot growers in Israel recently introduced practice of utilization of combination of stabilized hydrogen peroxide (Tsunami® 100) or yeast commercial product (Shemer™) with brushing of carrots before storage to remove the outer peel of the root [Eshel et al. 2009]. Also, hitosan coatings delay microbial spoilage and exhibit positive effects on the colour and texture of carrots during long storage [Leceta et al. 2015]. Postharvest treatments and storage conditions such as storage temperature and relative humidity usually have distinct effects on root vegetables quality atributes and texture properties [Ilić et al. 2013].

The most important quality attributes of carrots for fresh market are root size, shape, uniformity, colour, texture and sensory quality [Larsen and Wold 2016]. Storage potential depend of cultivar and the initial quality of carrot roots [Gajewski et al. 2010]. In addition, the storage conditions are among the most important factors affecting the quality of carrot roots [Suojala 2000, Seljasen et al. 2001, Gajewski et al. 2010]. Research results on the changes of total sugar content during storage period are sometimes contradictory. After the long-term storage, a significant loss of total sugar was determined [Suojala 2000, Poberezny et al. 2012]. In contrast, some studies report increase in these compounds compared to initial level [Istella et al. 2006, Gajewski et al. 2010]. Postharvest treatments and storage conditions such as storage temperature and relative humidity usually have distinct effects on root vegetables quality atributes and texture properties [Ilić et al. 2013].

In order to contribute to better understanding of influence of different postharvest treatments on carrot storage ability under optimal and in practice used harvest time and storage conditions the purpose of this study was to examine the effect of harvest time (November or January) and different postharvest treatments of carrots on the changes under optimal and suboptimal storage conditions.

MATERIALS AND METHODS

Soil characteristics

The experiments were performed in an experimental field located in the village of Debeljača (20°60'E, 45°07'N, altitude 76 m a.s.l., south part of Banat – northern Serbia) characterized with well drained and sandy soil with high organic matter and total N and P_2O_5 content and good K supplies (tab. 1). Experiment was conducted in three production seasons (2011–2013).

Table 1. Texture and chemical analysis of soil (0–30 cm) in carrot production

Dept	Sand (%)	Clay (%)	Silt (%)	pH in KCl	$CaCO_3$ (%)	Organic matter (%)	N-Total (%)	P_2O_5 mg 100 g^{-1}	K_2O mg 100 g^{-1}
0–30 cm	70	8	22	7.65	6.75	3.44	0.26	33.5	24.0

Plant material

The carrot (*Daucus carota* L.) cv. 'Maestro F_1' commercial hybrid for fall, autumn and winter open field production was used for the investigations. Common carrot cultivation practice was used in terms of soil preparation, plant density, nutrition, drip irrigation and crop protection. Seeds were sown at the beginning of July (second sowing, after peas). For fertilization 700 kg ha^{-1} of NPK fertilizer (8 : 16 : 24) and additional 200 kg ha^{-1} of ammonium sulphate and ammonium nitrate fertilizers during vegetation were applied.

Uniform carrot roots (about 150 g) at full maturity stage without signs of defects or diseases, of same size, shape and injury free, taken directly from the field, were selected for the experiment. The rules that at the harvest, root vegetables have to be firm and typical in colour, with achieved size sufficient to fill in the tips, and uniform taper from the shoulder to the tip was respected. The carrot roots were harvested, treated and stored went into storage on November 10^{th} (harvest I (H-I)) and January 5^{th} (harvest II (H-II)) while the measurement of carrot properties was performed on May 10^{th}.

Postharvest treatments

The following postharvest washing treatments have been conducted: 1) hot water washing and brushing (50°C for 1 min); 2) 1% H_2O_2 (tap water for 1 min); 3) 175 ppm NaOCl (tap water for 1 min); and 4) control, non-washed roots (with soil).

Storage condition

After the treatment, the carrot roots were stored until the same day (180 days in the storage for H-I and 60 days in the field + 120 days in the storage for H-II) at different storage conditions. The taproots were stored at 0°C, in a cold store with high relative humidity (RH 98%) in dark (S-1), or in a cooled room with a temperature of 0–2°C and uncontrolled relative humidity (RH 85–92%) (S-2).

For each postharvest treatment and storage regimen, 250 roots per replicate were sampled for analysis, with 4 replicates analysed in total.

Composition analysis

Dry matter content was determined by drying of samples at 105°C to the constant sample weight.

Sugar content in carrot roots was determined according to the Fehling method. Sugars were extracted with ethanol, then starch was hydrolysed using hydrochloric acid and the resultant glucose was extracted after neutralisation. Sugars were determined in the extracts after oxidation using copper reagent, linked to the reduction of potassium iodide to iodine, and titration of iodine with sodium thiosulphate.

For separation of sucrose, fructose and glucose ion chromatography was applied and the detection was performed with electrochemical detector.

Vitamin C content was determined by Tillman's method. The method is based on the extraction of L-ascorbic acid from the analysed samples in oxalic acid solution and measurement of its reaction with 2,6-dichlorphenolindophenol [SRPS EN 14130:2008].

Texture analysis

Texture analysis of carrot was conducted using a TA.XT Plus Texture Analyser (Stable Micro Systems, UK) according to the methods proposed by Belović et al. [2014]. Penetration force measurements were performed on three carrots from the each sample, using a 5 kg load cell. Penetration test was performed with a 2 mm diameter stainless steel flat cyl-

inder probe (P/2). Instrumental settings were taken from the sample project (GRP1_P2) of the software package (Texture Exponent Software TEE32, version 6.0, Stable Micro Systems, UK) and according to published data [De Belie et al. 2002]. Pre-test speed, test speed, and post-test speed were 1 mm s^{-1}, 2 mm s^{-1}, and 3 mm s^{-1}, respectively. Registration started when a trigger force of 1 g was reached, and the probe penetrated into the centre of carrot disc (xylem part) to a distance of 5 mm.

For the cutting/shearing test, which was carried out by Extended Craft Knife (A/CKB), carrot discs were prepared in the same way as for the penetration test. The test settings were taken from the sample project (GUM1_CKB) of the software package Texture Exponent Software TEE32, version 6.0 (Stable Micro Systems, UK).

Statistical analysis

Statistical software Statistica, version 12.0 (Statsoft Inc., Tulsa, OK, USA) was used for statistical data analysis. Data were subjected to three way factorial analysis of variance, while LSD test was used for evaluation of significance of differences between mean values of measured parameters ($P \leq 0.05$). Principal component analysis was used for the multivariate data analysis and explanatory investigation.

RESULTS AND DISCUSSION

The moisture content of cold stored carrots decreases with the time of storage. Carrots that exceed an 8% weight loss are less acceptable for the consumers [Kays and Paull 2004]. Due to the fact that the peel of carrot roots is very thin and highly water-permeable, low air humidity reduces shelf life and thus increases the shrivelling of carrot roots. Weight loss (WL) is the most important cause of postharvest losses of carrots and depends on the stage of maturity (harvest date), storage condition and the postharvest treatment.

In this study (tab. 2) it was found that for the first harvest (H-I) after SP the lowest WL (3.20%) was determined under S-1 storage regime for H_2O_2 treatment. All washing treatments contributed to significantly lower WL in comparison to unwashed-control roots under S-1 storage regime. Under S-2 storage regime the highest WL (34.51%) has been noted for hot water treatment. Smilarly high WL (36%) was recorded after 112 days of carrot storage [Istella et al. 2006] with suggestion that such result could be related to storage temperature (4–10°C), water transpiration in stored roots and the natural process of cell sap concentration.

For the carrots from the second harvest significantly higher WL after SP was observed for unwashed-control roots under both storage regimes (12.35% and 16.84% for S-1 and S-2, respectively). The lowest WL for the carrots from the second harvest under S-1 storage regime was recorded also in the case of treatment with H_2O_2 (5.98%). However, no significant differences in WL of carrots were observed between washing treatments (H_2O_2, NaOCl and hot water) neither under the S-1 nor under the S-2 storage regime. Commercial storage of carrots resulted in water losses of 15% fresh weight over a 3 month period [Ng et al. 1998]. Our results prove that the level of WL under adequate storage regime, like S-1 (temperature 0°C and RH above 98%) in our research, can be much lower especially if prestorage washing treatments are applied. However, deviation of storage conditions from optimal, in S-2 can result in significantly higher WL. The rate of carrot water loss is affected by the surface area of the root, the water vapour pressure deficit and air velocity [Correa et al. 2012]. Water loss due to transpiration results in shriveling, loss of bright colour and increased risk of postharvest decay.

Based on our experimental results after SP no statistically significant differences were recorded in dry matter (DM) content among the postharvest treatments and in comparison to the unwashed carrots-control independently of the storage conditions (S-1 or S-2). Storage regime S-2 for the both harvest times and all washing treatments and control roots resulted in a significant increase of DM. The increase of DM may partially be the consequence of desiccation, which in turn leads to the DM concentrating effect. Since the washing treatments (except the hot water treatment under S-2 storage regime) prevented excessive weight loss, the DM content of carrots was maintained at lower level in carrot roots from S-1 storage regime (tab. 2).

Table 2. Weight loss (WL), dry matter (DM) and total sugar content (TSC) in carrot roots from the first and the second harvest time in dependance of storage regime and postharvest treatments

	First harvest (H-I)					
	WL (%)		DM (%)		TSC (%)	
	S-1	S-2	S-1	S-2	S-1	S-2
T_0			10.96		5.78	
Control	7.32^{Ab}	31.63^{Aa}	11.48^{Ab}	15.39^{Aa}	5.78^{Ab}	8.39^{Aa}
H_2O_2	3.20^{Bb}	21.73^{Ba}	10.82^{Ab}	14.42^{Aa}	5.91^{Ab}	7.45^{Ba}
NaOCl	3.38^{Bb}	18.60^{Ba}	11.07^{Ab}	13.67^{Aa}	5.69^{Ab}	7.03^{Ba}
Hot water	4.85^{Bb}	34.51^{Aa}	10.33^{Ab}	13.28^{Aa}	5.41^{Ab}	6.94^{Ba}
	Second harvest (H-II)					
T_0			10.82		5.83	
Control	12.35^{Ab}	16.84^{Aa}	11.85^{Ab}	12.53^{Aa}	6.05^{Aa}	6.51^{Aa}
H_2O_2	5.98^{Bb}	13.08^{Ba}	11.58^{Ab}	12.86^{Aa}	6.03^{Ab}	7.03^{Aa}
NaOCl	7.35^{Bb}	11.97^{Ba}	11.59^{Ab}	12.77^{Aa}	6.10^{Ab}	7.19^{Aa}
Hot water	9.59^{Bb}	14.05^{Ba}	11.71^{Ab}	13.72^{Aa}	6.03^{Ab}	7.52^{Aa}

Storage regime: S-1 (0°C; 98% RH), S-2 (0–2°C; 85–92% RH); T_0 – harvest time (initial value)
Different superscript letters indicate significant differences according to LSD test ($P \leq 0.05$)
A, B – treatments (column); a, b – storage regime (row)

Gajewski et al. [2010], in the storage experiment with eight carrot cultivars after 6 months of storage, obtained similar results with respect to the increase in the dry matter content (an average for all the cultivars was 1.5%). Even more expressed DM content increase was also reported after six months of storage, reaching 2.2% to 3.4% [Poberezny et al. 2012].

Carrots accumulate sugars as they mature in the field. High sugar content improves eating quality, increases storage potential and supports maintaining of the moisture in the roots during storage. No significant differences were observed in the total sugar content (TSC) between carrots from the second (5.83%) and from the first harvest (5.78%). Our experimental results indicate that under S-1 storage regime (optimal conditions) TSC remains unchanged independently of the harvest time and the prestorage root washing treatments. Storage under S-2 storage regime (higher temperature and low humidity) for both harvest times and for all washing treatments and control roots, resulted in significant increase in TSC (tab. 2) but significant differences between washing treatments and the unwashed roots-control were observed only in the case of the first harvest.

Research results on the changes of total sugar content during storage period are sometimes contradictory. In terms of sugar content, some studies report increase compared to initial level [Gajewski et al. 2010]. The sugar content of carrot (Bolero) was almost doubled during the 112 d storage while its weight decreased more than 30% [Istella et al. 2006]. Several other studies oppositelly found little or no differences in sugar level during storage period [Poberezny et al. 2012]. The total amount of sugars does not decrease much during cold storage, and storage losses usually increase linearly with time.

Sucrose is the predominant transport and storage sugar in carrot roots at maturity, but its content is affected by environment and harvest time. In our research in carrot roots from first harvest sucrose content was higher (3.21%) than in the carrot roots from second harvest (2.79%). Storage condition had a highly significant ($P \leq 0.001$) effect on the changes in sucrose content in carrots after SP. As shown in Table 3, the sucrose content increased faster in carrots stored under S-2 than under S-1 storage regime. After SP differences between washing treatments and

Table 3. Contents of sucrose, glucose and fructose in carrot from first and second harvests depend on storage regimens and postharvest treatments

	First harvest (H-I)					
	Sucrose (%)		Glucose (%)		Fructose (%)	
	S-1	S-2	S-1	S-2	S-1	S-2
T_0	3.21		1.18		1.23	
Control	4.16^{Bb}	5.74^{Aa}	0.86^{Bb}	1.38^{Aa}	0.77^{Cb}	1.12^{Ba}
H_2O_2	3.57^{Cb}	4.89^{Ba}	1.26^{Aa}	1.23^{Aa}	1.21^{Ba}	1.26^{Ba}
NaOCl	3.39^{Cb}	4.52^{Ba}	1.29^{Aa}	1.18^{Aa}	1.03^{Ba}	1.27^{Ba}
Hot water	3.25^{Cb}	4.06^{Ba}	1.31^{Aa}	1.32^{Aa}	1.34^{Aa}	1.45^{Aa}
	Second harvest (H-II)					
T_0	2.79		1.36		1.50	
Control	4.36^{Aa}	4.46^{Aa}	1.06^{Bb}	1.14^{Bb}	0.88^{Bb}	1.02^{Bb}
H_2O_2	3.77^{Bb}	4.40^{Aa}	1.36^{Aa}	1.19^{Bb}	1.08^{Ba}	1.14^{Aa}
NaOCl	3.89^{Bb}	3.64^{Bb}	1.24^{Ab}	1.40^{Aa}	0.95^{Bb}	1.22^{Aa}
Hot water	4.24^{Aa}	4.51^{Aa}	1.28^{Ab}	1.34^{Aa}	0.97^{Bb}	1.25^{Aa}

Storage regime: S-1 (0°C; 98% RH), S-2 (0–2°C; 85–92% RH; T_0 – harvest time (initial value)
Different superscript letters indicate significant differences according to LSD test ($P \leq 0.05$)
A, B – treatments (column), a, b – storage regime (row)

unwashed-control roots are also in majority of cases statistically significant, while in majority of cases there are no statistically significant differences among the washing treatments.

Glucose and fructose contents were much higher in carrot roots from the second (1.36%) than in the roots from the first harvest (1.18%). The washed carrot roots stored under both storage regimes did not exibit significant change in the glucose content after SP. The rate of glucose reduction in unwashed control roots (0.86%) after SP at S-1 storage regimen was significant ($P < 0.05$).

The decrease in fructose content in carrots during the storage was highly dependent ($P \leq 0.01$) on the storage condition (tab. 3). The rate of reduction with the progression of storage time under S-1 and S-2 storage regimes was not significant ($P > 0.05$). Washing treatment significantly decreases ($P \leq 0.05$) the fructose content of carrots during storage. The fructose content of unwashed carrots decreased more intensivelly during the storage period under both storage regimes. In this paper we present data indicating that fructose occurs in quantities approaching one-half of the total reduction sugar present.

Most experiments record only minor changes in the glucose content in root vegetables during cold storage. Thus, Bufler and Horneburg [2013] found that extensive breakdown of sucrose to glucose and fructose did not occur during the cold storage of parsnip roots, since glucose concentations increased only marginally relative to sucrose concentrations [Ilić and Šunić 2015]. The increase in monosaccharides could be affected by a high and unstable temperature in a mound, accelerating the respiration process, and by the intensive growth of leaves and forking at the end of storage.

The content of vitamin C in carrot can be influenced by various factors such as differences among genotypes, climatic conditions and cultivation practices, maturity and harvesting method, and postharvest handling procedures. The stability of vitamin C in carrots can be influenced by factors from pre-harvest to harvest and post-harvest handling [Leong 2012]. Temperature management after harvest is the most important factor to maintain vitamin C levels in vegetables. Losses are accelerated at higher temperatures and with longer storage durations.

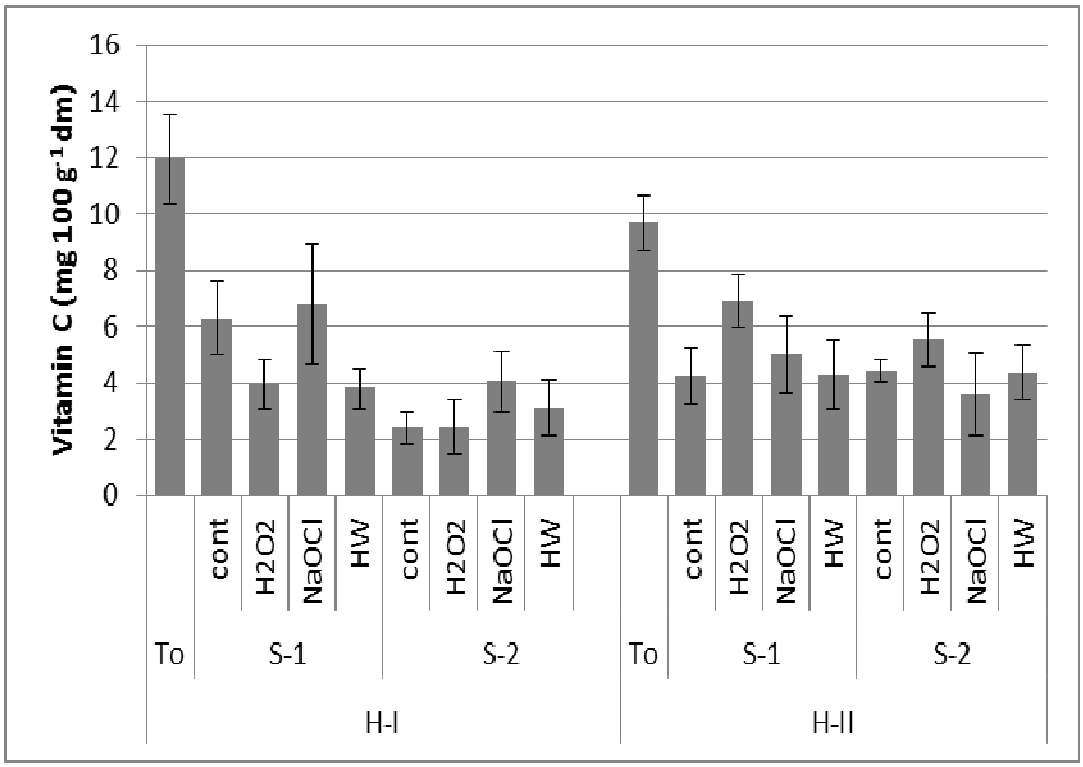

Fig. 1. Effect of postharvest treatments and storage conditions on vitamin C (mg·100 g^{-1} dm) content; H-I Harvest first, H-II Harvest second; T_0 – harvest time; S-1 (0°C and 98% RH), S-2 (0–2°C and 85–92% RH) – storage regime

Literature reports the vitamin C content in carrot roots to be from 0.25 to 3.50 mg 100 g^{-1} [Singh et al. 2012] to 8.00 mg 100 g^{-1} [Belitz et al. 2008]. These levels are similar to those obtained in the present study. Vitamin C decreased significantly during carrot storage (fig. 1). At the end of storage after 180 days (d), the vitamin C content was significantly reduced, particularly under S-2 storage regime for the carrot roots from the first harvest. Depending on the post-harvest treatment, the loss of vitamin C also varied from 28% for H_2O_2 treatment in the second harvest and under S-1 storage regime, up to 80% for the first harvest and unwashed- control roots under S-2 storage regime. In general the lowest reduction of vitamin C content was observed for NaOCl treatment under both storage regimes in the first harvest and for H_2O_2 treatment under both storage regimes in the second harvest.

Vitamin C loss was observed also by Matejkova and Petrikova (2010) after 30 days of storage, with a 47% reduction on average. The decrease in vitamin C content with storage duration was attributed to oxidation of ascorbic acid to dehydro-ascorbic acid by the enzyme ascorbic acid oxidase [Jany et al. 2008]. During a four-month carrot storage, vitamin C content decreased by ~1.7 times, and after a six-month storage vitamin C content decreased by 3.3 times compared to fresh carrots [Augšpole et al. 2013]. Matejkova and Petrikova [2010] reported a 15% vitamin C loss after 14 days storage at 4°C.

In order to summarize the significance of investigated factors on changes in carrot properties sum of squares of three way ANOVA are presented in Table 4 for harvest time (H-I and H-II), storage conditions (S-1 and S-2) and prestorage washing treatments (H_2O_2, NaOCl, hot water and unwashed) and their

Table 4. Significance of influence of harvest time, storage conditions and prestorage treatments and their interactions on properties of carrot roots after SP (ANOVA sum of squares)

Chemical properties	DM	TS	TSC	Vit. C	Succ	Glu	Fru
Harvest	0.639	0.005	0.679	0.103	0.004	0.006	0.165
Storage condition	62.15**	22.880**	2.498	0.085	9.901**	0.051	0.443
Treatment	0.791	0.108	0.652	0.028	1.836**	0.095	0.200
Harvest × Storage condition	11.70**	1.665	0.146	0.057	2.092**	0.013	0.000
Harvest × Treatment	2.357	1.112	0.065	0.142	0.736	0.007	0.045
Storage condition × Treatment	0.221	0.080	0.041	0.030	0.063	0.086	0.025
Harvest × Storage condition × Treatment	0.772	0.691	0.157	0.026	0.164	0.066	0.019
Error	1.238	1.250	0.827	0.072	0.406	0.348	0.177

** significant for $P \leq 0.05$

Table 5. Force of penetration (kg) and flexibility of carrot root in the dependence of the storage regime, prestorage treatments and harvest time

Harvest time	Force of penetration					
	Days of storage	Storage regime	Control	H_2O_2	NaOCl	Hot water
First	T_0	1446.1^{f}				
	T-180	S-1	1407.0^{e,f}	1243.0^{b,c}	1546.4^{g}	1119.6^{a}
		S-2	1272.2^{b,c,d}	1483.3^{f,g}	1243.1^{b,c}	1277.2^{b,c,d}
Second	T_0	1402.5 ^{e,f}				
	T-120	S-1	1266.5^{b,c,d}	1355.0^{c,d,e}	1224.4^{b}	1392.7^{e,f}
		S-2	1364.7^{d,e}	1528.4^{g}	1375.7^{d,e,f}	1316.5^{b,c,d,e}
Harvest time	Flexibility					
	Days of storage	Storage regime	Control	H_2O_2	NaOCL	Hot water
First	T_0	44.52^{f}				
	T-180	S-1	6.53^{a,b}	7.36^{b,c,d,e}	7.80^{c,d,e}	6.50^{a,b}
		S-2	7.24^{b,c,d,e}	7.74^{c,d,e}	7.72^{c,d,e}	6.45^{a,b}
Second	T_0	44.34^{f}				
	T-120	S-1	6.45^{a,b}	6.34^{a,b}	5.78^{a}	6.98^{b,c,d}
		S-2	8.09^{d,e}	8.15^{e}	6.93^{b,c}	8.32^{e}

T_0 – harvest time (initial value); T-180 – first harvest (180 days of storage); T-120 – second harvest (120 days of storage)
Storage regime: S-1 (0°C, 98% RH), S-2 (0–2°C; <90% RH)
Different superscript letters indicate significant differences according to LSD test ($P \leq 0.05$)

interactions. The results point out that harvest time did not exibit significant influence on any of analysed carrot quality parameters. Storage conditions affected significantly dry matter content (DM), total sugar (TS) and succrose (Succ) content, while investigated washing treatments significantly influenced only the succrose content. Interaction of harvest time and storage conditions exhibitied significant influence on dry matter and succrose content and no other interaction were proven to be of significant influence.

The root should be characterized by an appropriate hardness [Belović et al. 2014]. Texture is one of the most important criteria for quality evaluation, ranging from decision about readiness to harvest to assessing the impacts of postharvest handling and processing operation on product shelf-life.

Studies of the carrot root present a number of technical problems due to the specific morphological structure, high hardness and firmness of the carrot root compared to other vegetables. It is quite difficult to follow structural changes in the carrot root and its texture because it is composed of morphological parts (phloem and xylem) that differ in microscopic structure. During storage, tissue firmness is lost due to cell wall breakdown and loss of turgidity.

The required force to break the carrot root (force of penetration) is an indicator of root firmness. The greater the force needed, the firmer the root. Harvest time did not affect the force of penetration. Storage regime influenced this parameter significantly ($p = 0.05$), as did prestorage treatments ($p = 0.01$) (tab. 5). The interaction of all applied treatments in all combinations was statistically significant, indicating that storage regimen and postharvest treatments prior to storage affected this indicator of carrot quality in a complex, interactive way.

The firmness of carrot before and after storage is very important parameter of root quality. Stored samples in some cases required higher force for cutting than fresh carrot samples. Force of penetration (kg) significantly increased in the roots from first harvest with NaOCl treatment during storage in the S-1 storage regime, in relation to the root from the control, unwashed root (tab. 5).

Our findings that hardness may increase during storage and that this depends on the storage conditions is in agreement with findings by Chen and Opara [2013], who found that pretreating carrot samples with higher concentration of $CaCl_2$ (from 0.50% to 1.0%, at 25°C) resulted in a significant increase in hardness.

Application of NaOCl treatment on roots from the second harvest and under S-2 storage regime in the first harvest did not lead to in an increase in the force of penetration. In contrast, carrot roots from the first harvest under S-2 storage regime and roots from the second harvest under S-1 storage regime showed statistically significant reduction in the force of penetration. Statistically significant increase in the force of penetration was recorded also in the second harvest with H_2O_2 treatment for roots stored under S-2 storage regime. The application of this treatment to the roots from the first harvest stored under S-2 storage regime resulted in no change in forces of penetration, while for the roots from the first harvest stored under S-1 storage regimen the force of penetration decreased significantly. It was reported that after storage, a 1.05 times higher cutting force needs to be applied to stored carrots compared to fresh carrots [Augšpole et al. 2013]. This is expected, as carrots contain about 90% water, which gives rigidity to the texture.

The application of hot water treatment to the roots from the first harvest resulted in a decreased force of penetration, which is significantly lower after 180 d of storage compared to the power of penetration at the harvest time. For the second harvest there was no statistically significant change in this indicator. During storage, toughening takes place, associated with an increase of fibrousnesses, which devalues the quality of the roots.

The carrot root elasticity was not affected by harvest time or by the applied treatments, while storage regime significantly influenced root elasticity ($p = 0.01$). The interactions of all mentioned treatments, except for the interaction of storage regime and treatment as well as harvest time and treatment interaction, were not statistically significant.

Regardless of treatment, duration and storage regime, a considerable loss of carrot elasticity was recorded after 180 d of storage (tab. 5). Although not statistically significant, an effect of harvest date on the elasticity of carrot after storage can be observed between control and treatments with H_2O_2 and hot water under S-2 storage regime, compared to a much lower root elasticity observed after treatment with NaOCl under S-1 storage regime for the roots from the second harvest.

Carrots from the first harvest were characterized with a steady elasticity, with the exclusion of lower values obtained for the roots from both storage regimes treated with hot water and carrots from control kept under S-1 storage regime; with elasticities ranging between 6.45 and 6.53, and higher values for carrots from second harvest (control root, treatments with H_2O_2 and hot water) stored under the S-2 storage regime, with elasticity from 8.15 to 8.32.

Table 6. Correlation coefficients for carrot root properties parameters with the main principal components (PC)

	DM	TS	Vit. C	Succ	Glu	Fru	PF	F
PC1 (46%)	0.966	0.987	–0.403	0.854	0.374	0.443	0.336	0.519
PC2 (26%)	0.150	0.038	0.474	0.455	–0.706	–0.798	0.680	0.074
PC3 (10%)	–0.113	–0.042	0.649	–0.198	0.201	0.058	0.433	0.606

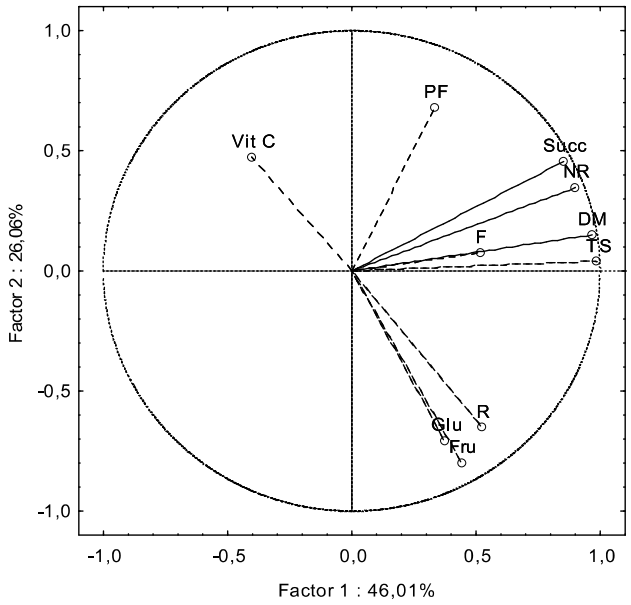

Fig. 2. Relations among principal components and carrot quality traits; DM – dry matter content, TS – total sugar content, R – reducing sugars, NR – non reducing sugars, Succ – succrose content, Glu – glucose content, Fru – fructose content, PF – penetration force, F – flexibility, Vit C – vitamin C content

For obtaining of aditional insight into interaction of investigated factors and carrot quality traits multivariate analysis of principal components was conducted. The studied variables were presented with first two principal components, which explained 72.07% of the total variability, the first principal components 46.01% and second 26.06%. The third principal component explains only 10% of total variability. The first principal component, based on correlations between variables and principal components (tab. 6) is influenced mainly by the dry matter content, total sugar and succrose content. High correlation with the second principal component was observed in the cases of glucose, fructose and penetration force as the indicator of carrot hardness. The third principal component was in the highest correlation with vitamin C content.

Graphical presentation of relations between first two principal components (fig. 2) that explain almost ¾ of registered variability (72.07%) points out that positive values of the first principal component (PC1) are related with higher dry matter, total sugars and succrose content, positive values of the second principal component are related to higher values of the penetration force indicating firmer roots, while the negative values of the second principal componet are related to higher content of monosacharides (glucose and fructose).

Graphical interpertation presenting position of applied treatments in the factorial plain as a result of variation of analysed quality properties is presented in Figure 3 (A, B and C).

From the principal component analysis (fig. 3A) it is obvious that the main factor based on which analyse carrot samples differentiate are the storage regimes (S-1 and S-2). Storage regimes are clearly separated by the first principal component (PC1) which is mainly influenced by dry matter content, total sugar and succrose content (tab. 6) and explains almost half of registered variability (46.01%). The other observation is that the influence of the second principal component is more expressed in the case of S-1 storage regime i.e. optimal storage conditions

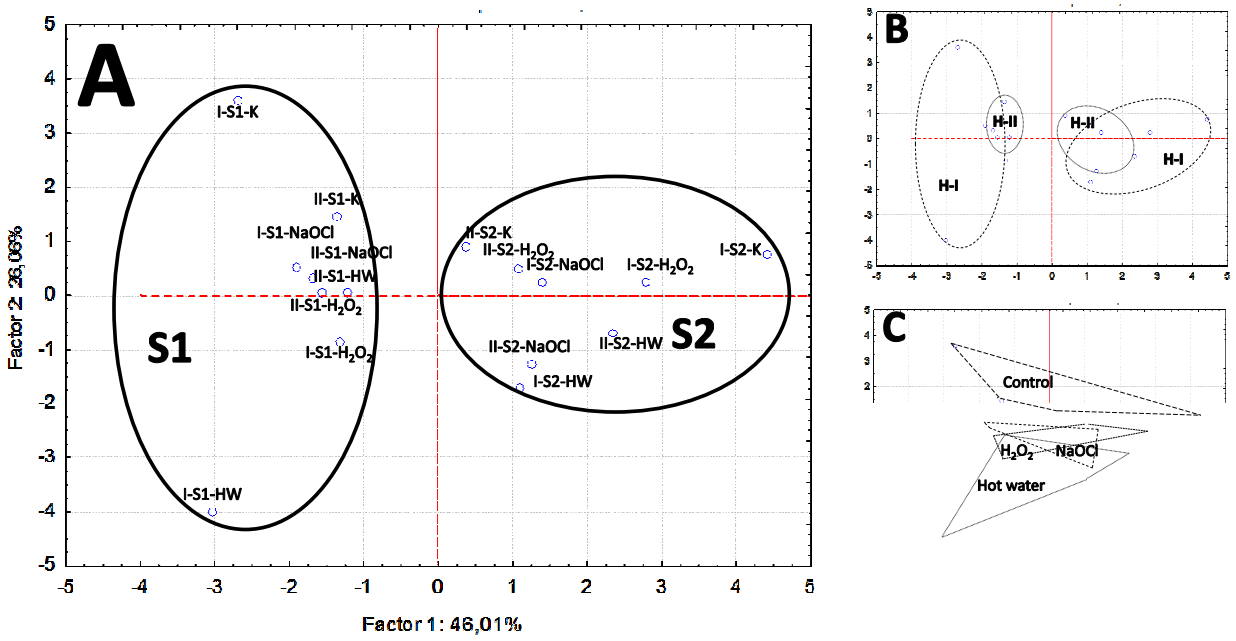

Fig. 3. Presentation of investigated treatments in factorial plain (PC1 × PC2) and their dependence on investigated factors (harvest time, storage conditions and prestorage treatment; S1, S2 – storage regimes; H-I, H-II – harvest times; K – unwashed-control samples; HW – hot water treatment

(0°C, RH 98%). In the case of storage regime that deviates from optimal conditions (S-2) the influence of the second principal component (PC2) is much less expressed. As already emphasized the second principal component (PC2) is mainly influenced by monosacharides content (glucose and fructose) and by root hardness. However, by the second principal component (PC2) the prestorage washing treatments are separated (fig. 3C). Clear differences are observed between all prestorage washing treatments and the unwashed-control roots. The washing treatments with NaOCl and H_2O_2 overlap and no clear difference can be obeserved, while the hot water treatment differentiates, especially in the case of the fist harvest time. Differences based on the first principal component among samples from different harvest times and storage regimes are the highest for unwashed-control roots, somewhat less expressed for hot water treated roots and the least expressed for roots washed in NaOCl or H_2O_2 indicating that the washing treatments contribute to the decrease of susceptability of roots to harvesting time and storage conditions deviations.

Differentiation of carrot roots harvested in different terms (H-I and H-II) are also contributed to the first principal component (fig. 3B) but the differences are much less expressed than the differences between investigated storage regimes. Additional observation is that in the second harvest under both storage regimes differentiation among treatments is much lower. This observation points out that the prestorage treatments are much more effective when the roots are harvested before the winter.

CONCLUSIONS

Our results show that storage regime was main factor in maintaining quality (dry matter, carbohydrate composition, vitamin C and root texture) after SP. Storage regime (S-1) at an optimum temperature (0°C) with a high relative humidity 98% can be recommended for preservation of carrot quality during long storage periods. In the light of this investigation, it is evident that washing treatments (except hot water dips) can significantlly reduced mass loss, slow down changes and maintaining quality after harvest. Prestorage treatments are much more effective when the roots are harvested before the winter. Overall, washing treatments to be a cost-effective approach for maintainigs retail/eating quality as well as functional or bioactive properties that are associated with human health and wellbeing.

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