Quality of Root Vegetables during Prolonged Storage

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Summary

The objective of this study was to develop postharvest techniques and technologies of the most important root vegetables: carrots, celeriac and parsnip. Investigations included the effect of harvest maturity (harvest at November or January) and postharvest washing treatments (hot water, H_2O_2 and NaOCl and non-washed-control) of carrots (*Daucus carota* 'Bolero F_1'), parsnip (*Pastinaca sativa* 'Banatski dugi') and celeriac (*Apium graveolens var. rapaceum* 'Mentor') roots and effects on their quantitative and qualitative changes during different storage conditions (S-1; 0°C and 98% RH or S-2; 0-2°C and 85-92% RH). Water loss and quality changes in these vegetables roots were monitored after 120 and 180 days of storage period (SP). At the end of SP the percentage of water loss ranged from 3.20% (from first harvest inside the S-1 with H_2O_2 treatment) in carrot to 39.29% (from first harvest inside the S-2 in control) in celeriac root. The dry matter content (DM) increased during storage period. Total sugar content (TSC) in the roots depends on year and harvest time. During SP, total sugar content increased more in S-2 cooling room. The parsnip root was characterized by more hardness texture relative to the carrot and celeriac roots. During SP carrot root loses the flexibility. The most effective method of maintaining quality of root vegetables is optimal harvest time followed by prestorage washing treatments (H_2O_2 or NaOCl) and storage at optimum temperature (0 ºC) with a high relative humidity 98%.

Key words

root vegetables, harvest time, postharvest treatment, storage condition, quality

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Received: April 12, 2016 | Accepted: October 21, 2016

Introduction

Root vegetables are an important part of vegetable crop worldwide, and the most important field vegetable produced and consumed in Serbia. Root vegetables have many positive properties which should gain them an important part in the human diet, they are relatively cheap and can be locally produced and stored for a long time (Rydenheim, 2008). Carrot and other root vegetables are rich in bioactive compounds like carotenoids and dietary fibers, with appreciable levels of several other functional components having significant health-promoting properties (Sharma et al., 2012). Also, parsnip and celeriac are richer in vitamins and minerals than carrot, but they lack beta carotene.

In Serbia, carrots, parsnip and celeriac are harvested from October to November, and may be stored until May the following year before packaging and retail. In Norway, carrot is harvested from June to September, and like parsnip and celeriac may be stored until May the following year before packaging and retail. The most important quality attributes of carrots for fresh market are root size, shape, uniformity, colour, texture and sensory quality (Larsen and Wold, 2016). Carrots quality characteristics are influenced by both biotic and abiotic parameters, and after harvest, the critical operations are handling, storage and processing (Seljåsen et al., 2013). Carrots are vulnerable to water loss, and proper packaging will prevent desiccation and hence prolong the shelf life. Low temperatures and absence of ethylene and sufficient oxygen in the packaging headspace atmosphere are important to avoid quality deterioration (Seljåsen et al., 2013).

In the parsnip production areas of Serbia (South Banat region), the most common storage method which farmers employ is to leave the mature product unharvested in the field during the winter period and harvest only when the product is about to be sold (Ilić et al., 2015a). The advantage of keeping them in the soil (as they tend to shrivel and lose weight quite easily) over winter is an improvement in taste (root tastes sweeter) which occurs when exposed to frost as it converts starch into sugar. These storage methods can result in crop losses estimated to be as high as 25-30%, with damage mostly occurring when there is soil freezing (Ilić et al., 2013). Parsnips are harvested in the late fall, preferable after frost. The delicate structure of the parsnip root makes it particularly sensitive to mechanical damage which can occur during soil freezing.

Celeriac is not as widely used as some other root vegetables, perhaps because it is harder to prepare and clean (Eldin et al., 2011). Like other root vegetables celeriac is pretty good as an integrient. Several investigators pointed to many factors towards enhancement of celeriac production and quality. The celery nutritional value, texture and flavor may change with plant age and different zones of the plant. Harvest date play an important role on yield and quality, therefore the late harvest of celery plants improved the nutraceutical value (Guerra et al., 2010). One of the most important factors for quality is the genotype and harvesting date (Dambrauskiene et al., 2009; Guerra et al., 2010).

The harvested root is an underground organ that has been dug out of the soil while it was in full metabolic activity. Preference for long term storage of vegetable roots is reflected in low metabolic activity at low temperatures, as shown by the low respiration rate (Stoll & Weichmann, 1987) and can be stored for 6-8 months without loss of quality under optimal storage conditions (Ilić et al., 2015b). The two basic conditions, as recommended by previous researchers are a temperature of 0°C and a relative humidity of 98% (Afek et al., 1999; Eshel et al., 2009). During storage, tissue firmness is lost due to cell wall breakdown and loss of turgidity. Postharvest treatments and storage conditions such as storage temperature usually have distinct effects on root vegetables quality attributes and texture properties. All of these changes can be prevented by different methods including cold storage and postharvest washing treatments. Chlorination of process water is one of the primary elements of a proper postharvest sanitation program. Washing carrots with cold chlorinated water (4°C) and warm tap water (50°C), respectively, provided good microbiological safety paired with improved sensorial properties (Klaiber et al., 2005). In the last few years, carrot growers in Israel usually applied combined application with stabilized hydrogen peroxide (Tsunami® 100) or a yeast commercial product (Shemer™) and have begun to brush carrots before storage to remove the outer peel of the root (Eshel et al., 2009). According to Chen and Opara (2013) pretreating carrot samples with higher concentration of $CaCl_2$ (from 0.50% to 1.0%, at 25ºC) resulted in a significant increase in hardness ($p < 0.05$). Carrot quality was best maintained in needle perforated packages with a gas atmosphere close to air, giving no major weight loss, no ethanol formation and the lowest incidences of storage diseases at both chill and retail conditions (Larsen and Wold, 2016).

Having all this in mind, the aims of this paper were to establish the optimal harvest time for the best carrot, parsnip and celeriac quality and postharvest washing treatments to achieve a better control of the quantity and quality of root vegetables during storage period.

Materials and methods

Soil characteristics

The experiments were performed at the experimental field located in the village of Debeljača (20° 60’ E, 45° 07’ N, altitude 76 m, south part of Banat - North Serbia) during 2011-2013. The soil was well drained and sandy, rich in organic matter (3.44%), with high contents of total N (0.26%) and of P_2O_5 (33.5 mg 100 g^{-1}), well above the limit of values. The content of K_2O was in the limits of good supplies (24 mg·100 g^{-1}).

Plant material

Investigations included the most important root vegetables: a commercial hybrid of carrot (*Daucus carota* ‘Bolero F_1’) for open field production during fall, autumn and winter; an old local domestic cultivar of parsnip (*Pastinaca sativa* ‘Banatski dugi’) for open field production during autumn and winter; celeriac (*Apium graveolens var. rapaceum* ‘Mentor’) intended for long storage.

Carrots were cultivated in accordance to commonly accepted cultural practices, such as soil preparation, sowing date, plant density, nutrition, drip irrigation and protection of the crop. Basal dressing implied use of NPK fertilizer (formulation 8:16:24) in the amount of 700 kg ha^{-1}. During vegetation period top dressing was performed with ammonium sulphate and ammonium nitrate fertilizers, up to 200 kg ha^{-1}. Sowing was conducted at the beginning of July (second sowing, after peas). At harvest, root vegetables must be firm and typical in color, should have achieved sufficient size to fill in the tips and should have uniform taper from shoulder to tip.

Celeriac was cultivated by seedlings produced in polystyrene trays in greenhouse. Sowing for seedlings production was conducted in the first decade of the May. After 60 days well developed seedlings (with 3-4 true healthy leaves) were transplanted in the open field. Recommended culture procedures for commercial production of celeriac (planting date, plant density, nutrition, plant protection) were applied. Celeriacs were harvested after 130-160 days of transplanting.

Direct sowing of parsnip in the open field was performed at the beginning of July (second sowing, after peas) in accordance to commonly accepted recommendations for this vegetable (land preparation, sowing, plant density, nutrition, etc.). Medium sized parsnips are the best quality, preferably around 50-70 mm shoulder diameter and approximately 190-250 mm in length. Large coarse roots which usually have woody or fibrous centers should be avoided. For the experiment firm taproots without defects or diseases, of same size, shape and injury free were selected.

Harvest time

One of the purposes of this study was to examine differences between time of harvest (first harvest in November and second harvest in January) and quantitative and qualitative changes (after application of prestorage treatments) during different storage conditions. Uniform taproots without defects or diseases, of same size, shape and injury free, about 150 g, at their full maturity stage, picked directly from the field, were selected for the experiment. For the first harvest (November 15) roots were stored for 180 days (d). The second harvest was recorded in January 15, and the roots were stored for 120 d.

Postharvest treatment

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

Following treatment, the taproots were stored for 180 d from first harvest time or 120 d from second harvest at different storage conditions. The taproots were stored at 0°C, in a cold room (S-1) with high relative humidity (RH 98%) at dark, or (S-2) in a cooling room with a temperature of 0-2°C and uncontrolled conditions of relative humidity (RH 85-92%).

For each postharvest treatment and storage regimen, 25 roots per replicate were sampled for analysis, with 4 replicates analyzed in total.

Sugar analysis

Content of sugar of root vegetables was determined using the Fehling method. Sugars are extracted using ethanol, then starch is hydrolysed using hydrochloric acid and the resultant glucose is extracted after neutralisation. Sugars are 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.

Starch degradation in parsnip was monitored by applying Lugol solution to parsnip cross-sectioned pieces at harvest and after storage.

Penetration test

Texture analysis of carrot and parsnip was conducted using a TA.XT Plus Texture Analyser (Stable Micro Systems, UK). Measurements were performed on three carrots from the each sample, using a 30 kg load cell (Belović et al., 2014).

Penetration test was performed with a 2 mm diameter stainless steel flat cylinder probe (P/2). Instrumental settings were taken from the sample project (GRP1_P2) of the software package (Texture Exponent Software TEE32, version 6,0,6,0, Stable Micro Systems, UK), and according to published data (De Belie et al., 2002). 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

Data were analyzed using the statistical software Statistica (Statistica, version 12.0). All data were subjected to two way factional analysis of variance by LSD test (level of significant at 0.01 and 0.05%).

Results and discussion

Carrots have low metabolic activity at low temperatures (rate of respiration at 0°C was 5-10 ml CO_2/kg·h) but are sensitive to wilting if not protected from water loss. The moisture content of refrigerated carrots decreases with time of storage. Water loss (shriveling) is the most important cause of postharvest losses of carrots and depends on the maturity stage (harvest date), storage condition and postharvest treatment. In this study (Tab. 1) it was found that at the end of the 180-day storage period the percentage mass loss ranged from 3.20% (inside the S-1 cooling room in treatment with H_2O_2) to 34.51% (inside the S-2 storage room with hot water treatment).

The same trend was observed also at second harvest where the lowest water losses in S-1 storage (5.98%) were recorded in treatment with H_2O_2, but more significantly the highest water losses were observed in S-2 storage in unwashed control roots (16.84%). In agreement with this observations, after 112 d of storage period the carrot (Bolero F_1) lost the most water (36%) from its mass (Istella et al., 2006). This could be related to storage temperature (4-10°C), water transpiration in stored roots and the natural process of cell sap concentration. Commercial storage of carrots resulted in water losses of 15% fresh weight over a 3 month period (Ng et at., 1998). 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. Because the peel of carrots is very thin and highly water-permeable, low air humidity reduces shelf life by increasing shriveling of carrots.

Table 1. Water loss (%) in carrot, parsnip and celeriac from first and second harvest depending of storage regime and postharvest treatments

	Carrot		Parsnip		Celeriac	
	S-1	S-2	S-1	S-2	S-1	S-2
			First harvest – stored for 180 days			
Control	7.32^{Ab}	31.63^{Aa}	6.55^{Ab}	22.19^{Ba}	11.68^{Ab}	39.29^{Aa}
H_2O_2	3.20^{Bb}	21.73^{Ba}	7.73^{Ab}	25.24^{Aa}	5.76^{Bb}	35.20^{Ba}
NaOCl	3.38^{Bb}	18.60^{Ba}	7.54^{Ab}	21.53^{Ba}	5.82^{Bb}	35.77^{Ba}
Hot water	4.85^{Bb}	34.51^{Aa}	8.57^{Ab}	23.00^{Ba}	9.09^{Ab}	36.97^{Ba}
			Second harvest – stored for 120 days			
Control	12.35^{Ab}	16.84^{Aa}	5.05^{Ab}	22.78^{Ba}	6.05^{Ab}	14.95^{Aa}
H_2O_2	5.98^{Bb}	13.08^{Ba}	4.78^{Ab}	26.00^{Aa}	5.36^{Bb}	12.35^{Ba}
NaOCl	7.35^{Bb}	11.97^{Ba}	4.71^{Ab}	21.46^{Ba}	4.93^{Bb}	12.11^{Ba}
Hot water	9.59^{Bb}	14.05^{Ba}	4.93^{Ab}	25.21^{Aa}	5.92^{Ab}	15.40^{Aa}

Storage regime: S-1 (0°C; 98% RH); S-2 (0-2°C; 85-92% RH); Different superscript letters in the column (A) and in the row (a) indicate significant differences according to Tukey's test ($p \leq 0.05$); A-treatments; a-storage regime

In parsnip roots from first harvest (15 November) stored for 180 days depending on the storage condition and disinfection treatment percentage of water losses ranged from 6.55% to 25.24%. Thus, the water loss of parsnip roots inside the S-1 sophisticated cooling room ranged from 6.55% in control (unwashed control roots) to a maximum water loss of 8.57% in washing treatment with hot water. A different trend between treatments was observed under S-2 storage regime, where the lowest water losses (21.53%) were recorded in treatment with NaOCl. The highest water losses (25.24%) were observed with H_2O_2 treatment (Table 1).

At the second harvest (15 January) roots were stored for 120 days regardless of storage regime, differences between prestorage treatments (washed roots) were not statistically significant compared to the control (unwashed root). Thus, in the S-1 storage regime, the water loss of parsnip in the control (5.05%) was not statistically different of hot water (4.93%), sodium hypochlorite (4.71%) and hydrogen peroxide (4.78%) treatments. Water loss of parsnip from the second harvest time-after 120 days of storage in the S-2 storage regime was significantly higher in the wash treatments with hydrogen peroxide (26.00%) and hot water (25.21%) compared to the control variant (22.78%) and treatment with sodium hypochlorite (21.46%).

In celeriac roots from first harvest (15 November) stored for 180 days depending on the storage condition and disinfection treatment percentage of water losses ranged from 5.76% to 11.68%. Differences between postharvest treatments were statistically significant compared to the control (unwashed root) regardless of storage regime. Thus, water loss of celeriac in control (unwashed roots) at S-1 cold storage was the largest (11.68%). Significantly lower water loss encountered in the treatment with sodium hypochlorite (5.82%) and hydrogen peroxide (5.76%).

In S-2 storage regime water loss of celeriac from first harvest (after 180 days of storage) was statistically significantly higher (39.29%) in the control root (without washing). Loss of water in the treatments with hot water (36.97%), sodium hypochlorite (35.77%) and hydrogen peroxide (35.02%) were significantly lower in comparison with control. The difference in harvest time (days of storage) in comparison with the storage regime was statistically highly significant (Table 1).

Differences between postharvest treatments (washed roots) are statistically significant regardless of storage regime. Thus, in the S-1 storage regime, the losses of water of celeriac from the control (6.05%) and hot water (5.92%) treatments in second harvest (stored for 120d) were significantly higher than the water loss from hydrogen peroxide (5.36%) and sodium hypochlorite (4.93%) treatments. In S-2 storage regime water loss of celeriac from the second harvest, after 120 days of storage was statistically significantly higher in the treatment with hot water (15.40%) and unwashed roots-control (14.95%) compared with hydrogen peroxide (12.35%) and sodium hypochlorite (12.11%) treatments.

In Table 2. changes in dry matter content (DM) of carrot, parsnip and celeriac depending of storage regime and postharvest treatments are shown. These experimental results indicate that harvest time and prestorage root washing (H_2O_2 and hot water) after the first harvest and storage of 180 d reduces dry matter content in comparison to unwashed roots only in S-1 storage regime. To the contrary, carrots from second harvest after 120 d had higher values of dry matter content in S-1 storage regime. Also, storage in S-2 storage regime (higher temperature and low humidity) from both harvest times in all washing treatments and control roots resulted in increasing of dry matter content. The increase in dry matter content may partially result from desiccation, which in turn leads to a concentrating effect on dry matter. Since washing treatment (except hot water treatment) prevented excessive moisture loss, the dry matter content of carrots was maintained better in samples from S-1 stored regime (Tab. 2).

DM content in parsnip root recorded the highest values at both harvest time (>20%) compared to other root vegetables. Unlike to other root vegetables dry matter content of parsnip increases in all treatments during the storage period. Increasing was more intense in S-2 storage regime.

In this research, the celeriac DM values varied from harvest time with average content of 11.86% at first harvest and 11.25% at second harvest. Dry matter in celeriac from first harvest time during SP (180 days) in S-1 storage regime stay at similar level in relation to the initial content. During same storage period in S-2 storage regime DM increased. Similar trend of increasing content of dry matter in the celeriac from second harvest

Table 2. Dry matter (%) changes in carrot, parsnip and celeriac from first and second harvest depending of storage regime and postharvest treatments

	Carrot		Parsnip		Celeriac	
			First harvest - stored for 180 days			
To	10.96		21.71		11.86	
	S-1	S-2	S-1	S-2	S-1	S-2
Control	11.48^{Ab}	15.39^{Aa}	25.03^{Ab}	29.28^{Aa}	11.64^{Ab}	16.37^{Aa}
H_2O_2	10.82^{Ab}	14.42^{Aa}	22.96^{Ab}	30.17^{Aa}	10.88^{Ab}	16.78^{Aa}
NaOCl	11.07^{Ab}	13.67^{Aa}	23.52^{Ab}	32.49^{Aa}	11.60^{Ab}	16.81^{Aa}
Hot water	10.33^{Ab}	13.28^{Aa}	23.64^{Ab}	34.06^{Aa}	11.82^{Ab}	14.97^{Aa}
			Second harvest - stored for 120 days			
To	10.82		21.10		11.25	
	S-1	S-2	S-1	S-2	S-1	S-2
Control	11.85^{Ab}	12.53^{Aa}	21.72^{Ab}	26.58^{Aa}	12.19^{Ab}	13.10^{Aa}
H_2O_2	11.58^{Ab}	12.86^{Aa}	21.43^{Ab}	26.93^{Aa}	11.94^{Ab}	13.50^{Aa}
NaOCl	11.59^{Ab}	12.77^{Aa}	22.13^{Ab}	26.19^{Aa}	12.34^{Ab}	14.19^{Aa}
Hot water	11.71^{Ab}	13.72^{Aa}	22.32^{Ab}	26.79^{Aa}	12.22^{Ab}	13.81^{Aa}

To-Harvest time; Storage regime: S-1 (0°C; 98% RH); S-2 (0-2°C; 85-92% RH); Different superscript letters in the column (A) and in the row (a) indicate significant differences according to Tukey's test ($p \leq 0.05$); A-treatments; a-storage regime

Table 3. Changes of total sugar content -TSC (%) in carrot, parsnip and celeriac from first and second harvest depending of storage regime and postharvest treatments

	Carrot		Parsnip		Celeriac	
			First harvest - stored for 180 days			
To	5.78		9.60		1.96	
	S-1	S-2	S-1	S-2	S-1	S-2
Control	5.78^{Ab}	8.39^{Aa}	13.90^{Ab}	16.17^{Ba}	3.29^{Aa}	4.05^{Aa}
H_2O_2	5.91^{Ab}	7.45^{Ba}	11.88^{Bb}	16.10^{Ba}	2.60^{Bb}	4.58^{Aa}
NaOCl	5.69^{Ab}	7.03^{Ba}	14.58^{Ab}	18.25^{Aa}	3.39^{Ab}	4.54^{Aa}
Hot water	5.41^{Ab}	6.94^{Ba}	13.38^{Ab}	19.28^{Aa}	3.24^{Aa}	3.16^{Ba}
			Second harvest - stored for 120 days			
To	5.83		9.89		2.52	
	S-1	S-2	S-1	S-2	S-1	S-2
Control	6.05^{Aa}	6.51^{Aa}	11.08^{Ab}	14.45^{Aa}	3.12^{Aa}	3.46^{Aa}
H_2O_2	6.03^{Ab}	7.03^{Aa}	11.77^{Ab}	14.21^{Aa}	3.23^{Aa}	3.47^{Aa}
NaOCl	6.10^{Ab}	7.19^{Aa}	11.49^{Ab}	14.08^{Aa}	3.59^{Aa}	3.88^{Aa}
Hot water	6.03^{Ab}	7.52^{Aa}	11.49^{Ab}	14.69^{Aa}	3.19^{Aa}	3.62^{Aa}

To- Harvest time; Storage regime: S-1 (0°C; 98% RH); S-2 (0-2°C; 85-92% RH); Different superscript letters in the column (A) and in the row (a) indicate significant differences according to Tukey's test ($p \leq 0.05$); A-treatments; a-storage regime

in both storage regimes was observed. Gajewski et al. (2010), in their storage experiment on eight carrot cultivars after 6 months of storage, obtained similar results with respect to the increase in the dry matter content (an average values for all the cultivars was 1.5%). After six months of storage, the increase in the dry matter content was 2.2% to 3.4% (Poberezny et al., 2012). Because the peel of carrots is very thin and highly water permeable, low air humidity reduces shelf life by increasing shriveling of carrots (Lentz 1966; Shibairo et al., 1997). Storage of carrots at 98–100% relative humidity combined with low temperature is required to preserve their content of health-related compounds, sensory quality and shelf life (Van den Berg and Lentz, 1966). This is mainly achieved by bulk storage in boxes with a perforated plastic lining to obtain humidity saturation. To maintain the necessary humidity during the distribution chain, carrots are generally packed in ventilated polyethylene bags (Pospišil et al., 1989).

The carbohydrates of root vegetables (carrot, parsnip and celeriac) were stored in the form of sugars. This contrasts with the potato where the carbohydrate is 90% starch. Total sugars were calculated as the sum of fructose, glucose and sucrose (Suojala, 2000). Thus, total sugar content in the roots of carrots varied between harvest time 5.78% to 5.83%. Parsnips contain the highest content of total sugars which impart a sweet taste to the vegetable. Total sugar content (TSC) in parsnip also differs between harvest time (9.60-9.89%). TSC in celeriac is the lowest in relation to the previous two species. The highest TSC in celeriac were observed in second harvest (2.52%) and lowest in first harvest (1.96%). During storage the TSC content increased more in S-2 storage regime in relation to the initial level (Tab. 3).

Table 4. Force of penetration (kg) of carrot root depending on the storage regime, prestorage treatments and harvest time

Harvest time	Days of storage	Storage regime	Control	H_2O_2	NaOCl	Hot water
First harvest	To	1446.1^{F}				
	Stored for 180 days	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 harvest	To	$1402.5^{E,F}$				
	Stored for 120 days	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}	$1375.7^{D,E,F}$	$1316.5^{B,C,D,E}$

To Harvest time; Storage regime: S-1 (0°C; 98% RH); S-2 (0-2°C; 85-92% RH); Different superscript letters ndicate significant differences according to Tukey's test ($p \leq 0.05$).

Table 5. Flexibility of carrot root depending on the storage regimes, prestorage treatments and harvest time

Harvest time	Days of storage	Storage regime	Control	H_2O_2	NaOCl	Hot water
First harvest	To	44.52^{F}				
	Stored for 180 days	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 harvest	To	44.34^{F}				
	Stored for 120 days	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}

Different superscript letters indicate significant differences according to Tukey's test ($p \leq 0.05$); T_o Harvest time; Storage regime: S-1 (0°C; 98% RH); S-2 (0-2°C; 85-92% RH)

During storage the sugar content increased more in S-2 storage regime During parsnip storage, sugar content increased more in S-2 storage regime. Accumulation of sucrose may raise the culinary quality of stored parsnip. Parsnip from both harvest time during storage in S-2 storage regime increased TSC (up to 19.28% in hot water treatment). This increase in sugar content is based mainly on account of the conversion of starch, which occurs after 2 to 3 weeks in cold storage. Low-temperature storage (2°C) decreased the starch content dramatically and concomitantly increased the sucrose content (Bufler, 2013).This allows the starches to convert into sugar, giving the parsnip its unique, sweet nutty flavour. Sugar accumulation was more rapid in roots stored at 0°C than at 10°C and in the core than in the cortex. Roots stored at 0°C were perceived to be sweeter than roots stored at 10°C or freshly-harvested roots, suggesting that an improvement in the eating quality of parsnip roots during short-term cold storage is possible, but would be temperature dependent (Shattuck et al., 1989).

The root should be characterized by an appropriate hardness (Belović et al., 2014). Texture is one of the key quality attributes, ranging from decision about readiness to harvest to assessing the impacts of postharvest handling and processing operation on product shelf life. The interaction of all applied treatments in all combinations was statistically significant, indicating that storage regime and postharvest treatments prior to storage in a complex, interactive way affected of this quality indicator of carrot.

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 (Table 4). Application of this treatment on roots from second harvest during S-2 storage regime did not result in an increasing. In contrast, root from the first harvest in S-2 storage regime and roots from the second harvest in S-1 storage regime obtained a statistically significant reduction in the force of penetration.

A statistically significant increase the force of penetration cross the root were recorded at the second harvest with H_2O_2 treatment, stored in S-2 storage regime. Application of this treatment from second harvest during S-2 storage regimes resulted in a statistically same level in forces of penetration, immediately after first harvest and after 180 days of storage, except in the roots from the first harvest during S-1 storage regime where force of penetration decrease significantly.

The application of hot water treatment in root from first harvest resulted in a decrease force of penetration which is significantly lower after 180 days of storage (1119.6) compared with the power of penetration at the harvest time (1446.1). In the second harvest there was no statistically significant change in this indicator. The interaction of all mentioned treatments except for interaction of regime of storage and treatment and also harvest time and the treatments is not highly statistically significant. Regardless of the treatment, duration and storage regime after 180 days of storage was recorded a considerable loss of carrot elasticity (Tab. 5).

The highest values of over 8 for the elasticity achieved in control and treatments with H_2O_2 and hot water in the S-2 storage regime. The lowest value of 5.78 for the elasticity recorder in treatment with NaOCl, from S-1 storage regime in root from second harvest time. Carrots from the first harvest were characterized by a steady elasticity, with the exclusion of lower values (roots from both storage regime, treated with hot water and a carrot from control kept in S-1 storage regime; with elasticity from 6.45 to 6.53) and higher values carrot from second harvest (control root, treatments with H_2O_2 and hot water) were stored in the S-2 storage regime; with elasticity from 8.15 to 8.32).

Table 6. Changes in the texture carrots, parsnip and celeriac after 45 days of storage

Storage period	Force of penetration (g)		
	Carrot	Parsnip	Celeriac
0 day	1446±131[a]	2047±484[a]	1462±276[a]
45 days	1391±186[a]	2074±536[a]	1291±343[a]

Results are presented as mean values ± standard deviation (n = 18);
The values marked with different letter within a column are significantly different (*p*<0.05)

Force of penetration of carrot root is at the same level of penetration force for celery root, while penetration the root of parsnip needs the greater force. No significant changes of penetration forces in carrot, parsnip and celeriac during the 45 days of storage were recorded (Tab. 6).

Conclusion

The principal factors which can be used to estimate the length of postharvest life of carrot, celeriac and parsnip include the time of harvest, postharvest treatments and storage conditions. Results of this study generally showed that the major factors affecting storage life are quantity loss (water loss) and quality changes (dry matter content, carbohydrate composition, texture, etc). The greatest crop loss was achieved in the ventilated storage rooms. Since this storage room underwent a large range of relative humidity fluctuation, it is possible this variable alone could account for the loss. The most effective method of maintaining quality of root vegetables by rapid cooling after harvest followed by storage at optimum temperature (0ºC) with a high relative humidity 98%.

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