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FRUIT QUALITY OF PLUM (*PRUNUS DOMESTICA* L.) CULTIVARS 'ČAČANSKA LEPOTICA' AND 'EMPRESS' AFTER COLD STORAGE

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Abstract

In order to respond to consumers' requirements, it is necessary to supply the market with high quality plum fruit. As the quality of the fruit starts to change immediately after harvest, cold storage is applied in order to maintain fruit characteristics, determined mainly in orchards. Since fruit quality and storage potential depend on cultivar, the aim of this research was to analyze and compare quality-related properties of 'Čačanska Lepotica' and 'Empress' before and after cold storage. Although examined cultivars have different ripening time, they are primarily grown for fresh consumption. Thus, all analyses were performed at harvest and after 28 days of cold storage (0–2 °C, 90–95% relative humidity), followed by a shelf life of three days at 20 °C. Fruit firmness, weight loss, susceptibility to *Monilinia* spp., soluble solids content, titratable acidity, antioxidant capacity, the concentrations of total phenolics, flavonoids and anthocyanins were monitored. After cold storage and subsequent shelf life, an increase in soluble solids content, antioxidant capacity, total phenolics and flavonoids were observed in both cultivars. Significant differences between fresh and stored plums were found in terms of fruit firmness. Fruit of 'Čačanska Lepotica' had higher content of soluble solids and anthocyanins and it was firmer in both analyses' dates compared to fruit of 'Empress'. However, its fruit was more susceptible to *Monilinia* spp. and had significantly higher weight loss than 'Empress' fruit.

Keywords: *Storage, Fruit firmness, Weight loss, Bioactive compounds.*

Introduction

Plum, as a highly perishable stone fruit, has limited shelf life, which represents a serious restraint for its adequate storage and transportation. Due to rapid ripening and softening, plum is usually marketed within a short period of time. However, meeting consumers' demands means supplying the market with high quality plum fruits for at least three weeks after harvest (Vangdal et al., 2007). Nevertheless, growers attempt to store plums in order to achieve better prices later in the season. Therefore, knowledge about fruit's behaviour during and after cold storage is of great importance for maintaining plum quality.

Antioxidants are molecules, which in low concentrations significantly inhibit the oxidation of the substrate (Halliwel et al., 1995). In order to protect biomolecules and tissue, antioxidants react with potentially dangerous free radicals. During this reaction, antioxidants are being oxidized, free radicals are scavenged and the oxidation process is hindered. Hence, the antioxidant capacity is one of the essential determinants of food biological value. Since the antioxidant capacity is largely dependent on the content of total phenolics, flavonoids and anthocyanins (Vinson et al., 2001), the present research evaluated the changes in the content of aforementioned compounds in fresh and stored plums. Although several studies have examined major indicators of plum quality (soluble solids content, titratable acidity, fruit firmness, weight loss) during storage (Mihalache Arion et al., 2014; Vangdal et al., 2007),

changes in bioactive compounds under unfavourable market's conditions (high temperature and low relative humidity) are still indefinite.
Cultivars and rootstocks play an essential role in determination of postharvest storage potential and quality of stone fruits (Crisosto and Costa, 2008; Crisosto et al., 1995). Thus, the aim of this study was to analyze and compare quality-related traits of two plum cultivars with different ripening time, 'Čačanska Lepotica' and 'Empress', before and after cold storage.

Material and Methods

Fruits of two plum cultivars 'Čačanska Lepotica' and 'Empress' (also known as 'Grossa di Felisio') were harvested at the optimal maturity stage for cold storage. Harvest date for 'Čačanska Lepotica' was 26th July 2019, whilst fruits of 'Empress' were picked on 10th September 2019. The fruits were obtained from the commercial orchard, located near Čačak, in which standard agricultural practices were applied. After transportation to the laboratory of Fruit Research Institute, Čačak, fruits were divided into two groups. One group of fruits was used for determination of fruit quality on the harvest date, whilst another group was stored for 28 days in a cold chamber at 0–2 °C and 90–95% relative humidity. In order to simulate market's condition, after removal from the cold chamber, fruits were kept at 20 °C for three days. Therefore, all analyses were performed in two terms, at harvest and after 28 days of cold storage followed by a shelf life of three days.
Twenty fruits of each cultivar were selected for the weight loss test (Korićanac et al., 2020). On every analyses' date ten randomly chosen plums per cultivar were used for determination of fruit's firmness by a hand penetrometer (model FT 327, T.R. Turoni, Forly, Italy); two measurements were made on opposite sides of the fruits and then averaged in order to obtain the mean value expressed in kg/cm^2. Soluble solids content (SSC) was measured on a digital refractometer (model MA871, Milwaukee Instruments, Rocky Mount, NC, USA) and expressed in %. Titratable acidity (TA) was determined by neutralization with 0.1 N NaOH to pH 8.2, using phenolphthalein as indicator. The results were expressed as a percentage (%) of malic acid. Measurements of pH of fruits' pulp were performed by a potentiometer (pH meter Mettler Toledo EL 20-Basic, Schwerzenbach, Switzerland). After removal of samples from cold storage and subsequent shelf life, the number of fruits infected by *Monilinia* spp. was registered.
Antioxidant capacity was determined by two methods, DPPH and ABTS assays. DPPH procedure was conducted according to the method described by Sanchez-Moreno et al. (1998), whilst the ABTS•+ radical cation scavenging activity was determined according to Re et al. (1999). For both aforementioned assays Trolox was used as a standard and the antioxidant capacity was expressed as millimole Trolox equivalent per 100 g fresh weight (mmol TE/100 g fw). Folin-Ciocalteu colorimetric procedure (Singleton et al., 1999) was used for evaluation of total phenolic content (TPC) and the results were shown as milligrams of gallic acid in 100 g fresh sample (mg GAE/100 g fw). Total flavonoids (TFC) were estimated by the aluminium chloride method (Zhishen et al., 1999). Results were expressed as milligrams of rutin equivalent (RE) per 100 g fresh weight. Anthocyanin quantification (TAC) was performed by the pH-differential method (Hosseinian et al., 2008); results were expressed as milligrams of cyanidin-3-glucoside equivalents (c-3-gE) per 100 g fresh weight. All analyses were conducted in three replicates.
The obtained data were subjected to the one-way analysis of variance (ANOVA, F test). Multiple comparisons of means were performed by the Tukey test ($p = 0.05$) using STATISTICA 7.0 software (Statsoft Inc., Tulsa, OK, USA). All data were reported as mean ± standard deviation.

Results and Discussion

Postharvest quality of plum needs to satisfy consumers' demands in terms of appearance, texture, flavour, nutritional value and safety. One of the major factors limiting storage potential of plums are weight loss and excessive softening. Weight loss results in shrinkage and shrivelling of fruits, which highly affects consumers' acceptance. 'Čačanska Lepotica' had higher weight loss in comparison with 'Empress' (Figure 1), which indicates more intensive transpiration during cold storage and subsequent shelf life in this cultivar. Similar results were reported by Guerra and Casquero (2008), who noticed a significant increase of weight loss (6%) after a three-day shelf life in plum cultivar 'Green Gage'.

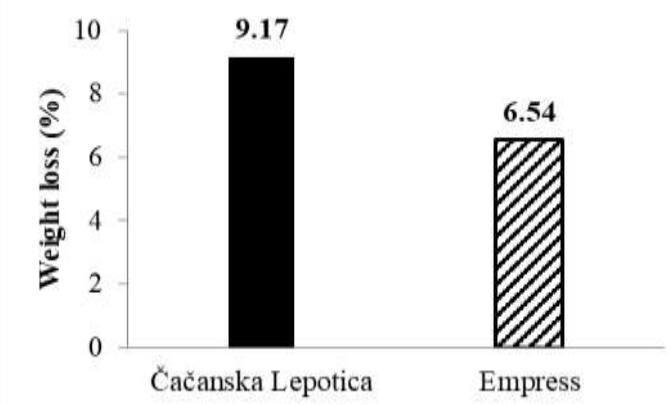

Figure 1. Weight loss in examined plum cultivars after 28 + 3 days of storage

As the result of structural changes of cell wall polysaccharides, particularly pectin solubilisation, fruit firmness rapidly decreased in both cultivars. In 'Čačanska Lepotica' the fruit firmness was reduced by 58.07% after shelf life, whilst 'Empress' had a higher loss of firmness (67.96%). Nevertheless, 'Čačanska Lepotica' had firmer fruit both at the harvest and after storage (Figure 2). Vangdal et al. (2007) reported that the reduction of firmness after two weeks of storage was cultivar dependant and it ranged from 15% to 37%.

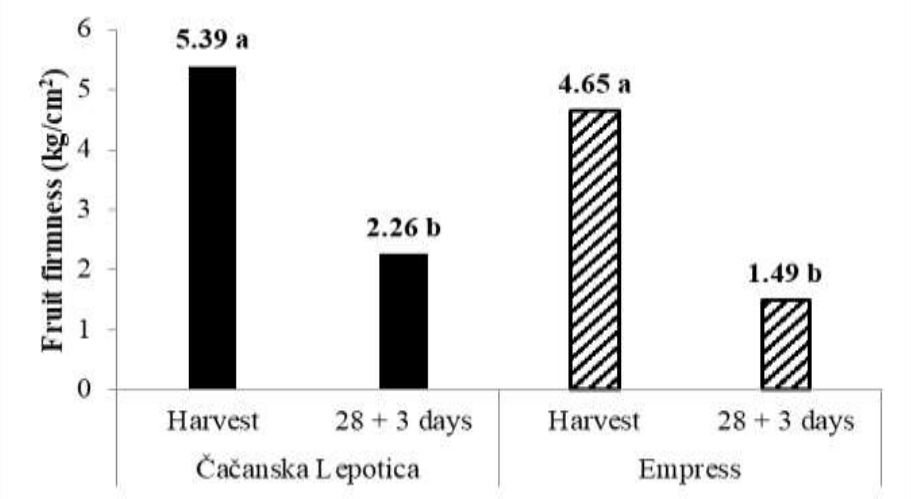

Figure 2. Fruit firmness of examined plum cultivars

Different letters indicate significant differences between analyses dates, according to the Tukey test.

Due to the strong correlation with palatability, SSC and TA are one of the most important quality indicators in plums. An increase of SSC during storage was observed in both examined cultivars (Table 1). On the contrary, TA decreased during the same period, and

consequently higher pH values were detected after storage. Similar findings were obtained by Vangdal et al. (2007) and Guerra and Casquero (2008). Crisosto et al. (2004) reported that plums with SSC ≥ 12% had the maximum consumer acceptance regardless of TA. However, the ratio between the contents of soluble solids and total acids (SSC/TA) is more closely related to the fruit quality than SSC or TA individually (Kader et al., 1982). SSC/TA ratio increased during storage in both cultivars, which is in agreement with the findings of Vangdal et al. (2007). According to the previously mentioned data, fruits of both 'Čačanska Lepotica' and 'Empress' had satisfactory quality-related properties after storage under simulated market's conditions.

Table 1. Soluble solids content (SSC), titratable acidity (TA), SSC/TA ratio and pH value in fruits of examined cultivars at the harvest and after storage

Parameter	'Čačanska Lepotica'			'Empress'		
	ANOVA	Harvest	28 + 3 days	ANOVA	Harvest	28 + 3days
SSC (%)	ns	14.33 ± 1.39	15.08 ± 1.27	***	12.40 ± 1.41 b	15.02 ± 1.98 a
TA (%)	*	1.11 ± 0.03 a	0.90 ± 0.08 b	**	0.97 ± 0.02 a	0.87 ± 0.01 b
SSC/TA	***	12.94 ± 0.26 b	16.76 ± 0.19 a	***	12.78 ± 0.30 b	17.26 ± 0.54 a
pH	***	3.31 ± 0.01 b	3.39 ± 0.01 a	*	3.24 ± 0.03 b	3.33 ± 0.02 a

The presence of different letters in the same row and for the same cultivar indicates that there is significant difference according to the Tukey test. *** statistically significant differences at $p \leq 0.001$; ** statistically significant differences at $p \leq 0.01$; * statistically significant differences at $p \leq 0.05$; ns – non significant difference

Plums are an important source of bioactive compounds, which prevent occurrence of many diseases (Stacewicz-Sapuntzakis et al., 2001) and highly contribute to the antioxidant capacity. High antioxidant capacity, which increased during storage, was observed in both cultivars, regardless of the applied assay (Table 2, Table 3). This is in compliance with the results obtained by Mihalache Arion et al. (2014), who evaluated antioxidant capacity, TPC and TAC of twelve plum cultivars, at the harvest and after storage.

Table 2. Antioxidant capacity evaluated by DPPH and ABTS assays and content of bioactive compounds (total phenolics - TPC, total flavonoids - TFC, and total anthocyanin - TAC) in 'Čačanska Lepotica' fruits

Parameter	'Čačanska Lepotica'		
	ANOVA	Harvest	28 + 3 days
DPPH (mmol TE/100 g fw)	**	1.42 ± 0.03 b	1.55 ± 0.02 a
ABTS (mmol TE/100 g fw)	**	1.30 ± 0.10 b	1.61 ± 0.02 a
TPC (mg GAE/100 g fw)	**	173.10 ± 5.02 b	215.00 ± 7.56 a
TFC (mg RE/100 g fw)	***	134.78 ± 0.92 b	185.67 ± 2.01 a
TAC (mg c-3-gE/100 g fw)	***	46.06 ± 1.03 a	35.35 ± 0.43 b

The presence of different letters in the same row indicates that there is significant difference according to the Tukey test. *** statistically significant differences at $p \leq 0.001$; ** statistically significant differences at $p \leq 0.01$

Although TPC in 'Empress' plums increased by 49.64% after cold storage and subsequent shelf life, it was still significantly lower in comparison with 'Čačanska Lepotica', in which TPC raised by 24.21%. However, storage period did not affect TFC in fruits of 'Empress.'

Table 3. Antioxidant capacity evaluated by DPPH and ABTS assays and content of bioactive compounds (total phenolics - TPC, total flavonoids - TFC, and total anthocyanin - TAC) in 'Empress' fruits

Parameter	'Empress'		
	ANOVA	Harvest	28 + 3 days
DPPH (mmol TE/100 g fw)	**	1.15 ± 0.01 b	1.32 ± 0.04 a
ABTS (mmol TE/100 g fw)	ns	0.97 ± 0.06	1.09 ± 0.07
TPC (mg/100 g fw)	*	96.90 ± 6.75 b	145.00 ± 21.04 a
TFC (mg/100 g fw)	ns	123.45 ± 1.12	124.42 ± 1.10
TAC (mg/100 g fw)	ns	9.46 ± 0.64	9.95 ± 0.12

The presence of different letters in the same row indicates that there is significant difference according to the Tukey test. ** statistically significant differences at $p \leq 0.01$; * statistically significant differences at $p \leq 0.05$; ns – non significant difference

Plum skin colour is an important external characteristic of the fruit, largely dependent on the content of anthocyanins. The obtained TAC in fresh fruits of 'Čačanska Lepotica' was in accordance with the concentrations reported for early plum cultivars (Mihalache Arion et al., 2014), whilst 'Empress' had surprisingly low concentration of these compounds. Interestingly, TAC in 'Čačanska Lepotica' plums decreased during storage, which is contrary to the results reported by Díaz-Mula et al. (2009).

The number of fruits infected by *Monilinia* spp. was determined after 28 days of cold storage followed by a shelf life of three days at 20 °C. 'Čačanska Lepotica' was extremely susceptible to this economically important pathogen with 45% infected fruits. Although Lee and Bostock (2007) reported that the presence of phenolic acids inhibited appressorium formation from germinated conidia and subsequent brown rot lesion development, 'Empress' plums, which contained lower TPC, did not have symptoms of infection in our research. However, it is difficult to compare the cultivars' susceptibility to fungal decay, as the fruits were harvested on different dates, under different climatic conditions. Thus, this result should be considered with caution.

Conclusions

Plum production and marketing require considering several aspects, including the choice of appropriate cultivar, not only in terms of yield but also in relation to fruit quality and storage potential. The present study indicated the difference in changes of quality-related properties during storage in two plum cultivars with different harvesting times. Despite the high susceptibility to *Monilinia* spp., 'Čačanska Lepotica' as an early season cultivar exhibited better postharvest fruit quality (firmer fruit, higher content of soluble solids and bioactive compounds). On the contrary, 'Empress' is a perspective cultivar due to its late harvest time. Nevertheless, it had lower weight loss after shelf life. The obtained results indicate that fruits of both examined cultivars, even after cold storage and shelf life, represent a good source of health-beneficial compounds.

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