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ORIGINAL ARTICLE

# Effects of ripening stage and postharvest treatment on apricot (*Prunus armeniaca* L.) cv. NS4 delivered to the consumers

Jasna Mastilović[1] | Žarko Kevrešan[1] | Maja Milović[2] | Renata Kovač[1] | Biserka Milić[2] | Nenad Magazin[2] | Dragana Plavšić[1] | Jelena Kalajdžić[2]

[1]Center of Food and Vegetable Products, Institute of Food Technology, University of Novi Sad, Novi Sad, Serbia

[2]Department of Fruit Growing, Viticulture, Horticulture and Landscape Architecture, Faculty of Agriculture, University of Novi Sad, Novi Sad, Serbia

**Correspondence**
Renata Kovač, Center of Food and Vegetable Products, Institute of Food Technology, University of Novi Sad, Novi Sad, Serbia.
Email: renata.kovac@fins.uns.ac.rs

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## Abstract

Fully ripe apricots ($I_{ad}$ < 0.1) were stored during 21 days at low temperature (1 ± 1°C) under different $CO_2$/packaging treatments: non treated, stored non-packed after 24 hr in 100% $CO_2$, stored packed in 100% $CO_2$ and stored in commercial micro perforations (MAP) bags in which $CO_2$ concentration reached up to 7%. Obtained results were compared with fruits harvested in commercial ripening stage ($I_{ad}$ 0.4–0.8), cold-stored for 21 days and subjected to 3 and 8 days of shelf life. Lower ethylene production and respiration rate, higher total soluble solids and sucrose and lower citric acid content characterizing fully ripe fruits in comparison to fruits harvested as commercially ripe even after prolonged postharvest ripening were noted as advantages of fully ripe fruits. Packaging in MAP bags seems to be the promising alternative for marketing of fresh apricots. Browning is the main quality deficiency which deserves further attention.

**Novelty impact statement:** Possibilities for distribution of apricots harvested as fully ripe fruit through the cold chain as alternative to distribution of commercially ripe apricots was investigated. Lower ethylene production and respiration rate, higher total soluble solids and sucrose and lower citric acid content were noted as advantages of fully ripe fruits delivered to consumers. Tissue browning, which depends on $CO_2$ concentration in apricot packaging units, was noted as the main problem limiting possibilities for distribution of fully ripe apricots.

## 1 | INTRODUCTION

Global production of apricots (*Prunus armeniaca* L.) exceeds 4 million tons annually. However, production of apricots is both, production region and production season limited. Season of apricot harvesting is characterized with span of less than 2 months. Production of apricots is concentrated mainly in southern Europe with Turkey being the main producer (Muftuoğlu et al., 2012) and Spain the main exporter (García-Gómez et al., 2020) of this fruit. Spatial limitation of apricot production is a consequence of severe reduction of apricot yields in regions characterized with high probability of low temperatures, frost and snow in early spring during apricot flowering (Milić & Vukoje, 2008) resulting in yield coefficient of variation of almost 50% with occasional incidence of 100% loss of yields (Milatović et al., 2013) due to damage of flower buds by low temperatures (Glišić et al., 2019).

Apricot as typical climacteric fruit is characterized with rapid degradation of fruit quality after the harvest. Shelf life of fully ripe apricot without cooling or other postharvest treatment is limited to just a few days, limiting thus the distribution of fresh ripe fruits to local markets. However, the processes of apricot degradation can be effectively retarded by cooling of fruits to close to zero temperatures. In addition to cooling, suppression of fruit respiration through the application of increased $CO_2$ concentration has also been proven as convenient technique for extension of apricot shelf life (Amoros et al., 2008; El-Oraby et al., 2014; Ezzat, 2018; Muftuoğlu

  

et al., 2012; Peano et al., 2014). According to Muzzaffar et al. (2018), an increase in the concentration of $CO_2$ to only 2%–3% exhibit effects on slowing of respiration rate resulting in extended storability and shelf life without negative impact on fruit quality, while Moradinezhad et al. (2018) reported that short shock treatment with high $CO_2$ reduced quality loss during latter cold storage of pomegranate. It has been suggested also that $CO_2$ treatment can be used as alternative to fungicide and chemical treatments (Moradinezhad et al., 2018).

In the practice, apricots are usually harvested in so called "commercial" ripening stage in which apricot fruits are characterized with firm flesh and fruit skin at breaker stage with traces of green tones and appearance of slightly expressed orange tones (Fan et al., 2018; Peano et al., 2014). In apricots in commercial ripening stage transformation of sugars, degradation of acids and synthesis of aromatic compounds as processes contributing to transformation of firm, tasteless unripe apricot to highly appealing fruit with balanced sugar/acid ratio and specific aroma have not yet been completed (Fan et al., 2018; García-Gómez et al., 2020; Zhang et al., 2019). During cold storage, most of ripening processes are slowed down, and short subsequent shelf life, limited by fruit firmness, is not sufficient for the development of taste, aroma and appearance characterizing fully ripe fruit.

The aim of the present research is to investigate the possibilities for distribution of fully ripe apricots through the cold supply chain with the application of different $CO_2$ and packaging treatment and to compare the quality and safety of fully ripe apricots with fruit harvested in commercial ripening stage and stored and marketed in conventional manner.

## 2 | MATERIALS AND METHODS

Apricot fruits, cultivar NS4 were cultivated at the Experimental field for fruit growing of Faculty of Agriculture, Novi Sad (45°19′ N and 19°50′ E, 86 m a.s.l.). Apricots were harvested on the same day, 119 days after flowering. DA meter (TR Turon SRL, Italy) was used to segregate fruits on the basis of ripening stage. Two lots of fruits were used: commercially ($I_{ad}$ value 0.4–0.8) and fully ripe ($I_{ad}$ value 0.0–0.1).

Commercially ripe apricots were placed in wooden crates and stored for 21 days in cooling chamber at low temperature (1 ± 1°C) and relative humidity (RH) 80 ± 10%. After 21 days, apricots were subjected to postharvest ripening and analyzed after 3 and 8 days of shelf life (at 24 ± 2°C without control of RH). Fully ripe fruits were subjected to different postharvest treatments with $CO_2$ and stored for 21 days (at 1 ±1°C and RH 80 ± 10%). The following $CO_2$ treatments were applied: (1) treatment with 100% $CO_2$ in sealed vessel during 24 hr and subsequent storage in wooden crates ($CO_2$-24 hr); (2) packaging in air tight packaging units (four-layer polyamide, thickness 70 μm) in which atmosphere was replaced completely with $CO_2$ ($CO_2$-100%); (3) packing in commercial MAP bags (Xtend®, StePac, Israel) with micro perforations (MAP). Non treated fruit placed in wooden crates were used as control (C). In packaged samples, $CO_2$ levels were monitored throughout the experiment with OXYBABY® 6.0 (WIT-Gasetechnik GmbH & Co KG T, Germany). In all air tight packaging units final $CO_2$ concentration was above 98%, while in commercial MAP bags with microperforations final $CO_2$ concentration varied from 6.5% to 7.0% Prior to analyses unpacked fruit were left for 12 hr to reach room temperature. Measurement of color and texture, ethylene and respiration rates, and chemical analysis were performed for freshly harvested fruit and for fruit after applied treatments of storage and shelf life. For chemical analysis 10 representative fruit were cooled at 4°C, quartered, pit was removed and 10 quarters were homogenized, placed in 3 L polyethylene bags with zip so that thickness does not exceed 50 mm and immediately frozen in dry ice.

Ethylene production and respiration rate were analyzed on approx. 250–300 g of apricot fruit, placed in 770 ml container and hermetically sealed with multilayer foil during 4 hr at 24°C (±2°C). Measurements for both, ethylene ($C_2H_4$) and carbon dioxide ($CO_2$) production were performed after harvest and after 21 days of cold storage. $CO_2$ concentration was analyzed directly in sealed containers using OXYBABY® 6.0 (WIT-Gasetechnik GmbH & Co KG T, Germany). For ethylene analysis, 2 ml of gas was sampled with plastic syringe, injected into 10 ml headspace vial sealed with silicone septa. Ethylene content was determined by gas chromatography (GC 7890, Agilent, USA), equipped with FID detector (Agilent, USA) and auto sampler (COMBIPAL, CTCAnalytics AG, Switzerland). The separation was performed on DB-WAX column, with temperature gradient from 60 to 150°C, flow rate 30 ml/min, and nitrogen ($N_2$) as carrier gas. Split injection was 10:1. Respiration (μl $CO_2$ $g^{-1}$ $h^{-1}$) and ethylene (nl $C_2H_4$ $g^{-1}$ $h^{-1}$) production rates were calculated from the $CO_2$ and $C_2H_4$ concentration difference before and 4 hr after sealing the dish, taking into account weight of fruit in the dish, its volume, volume of the dish and exact time from the moment of sealing the dish until the moment of sampling.

Water content was determined using termogravimetric analysis (TGA-701, LECO Co., USA). Total soluble solids (°Brix) were determined by digital refractometer ATR-ST plus (Schmidt + Haensch, Germany) on previously homogenized apricot samples at 20°C.

Total phenol and flavonoid extraction was carried out from 1 g of homogenized sample in two steps (Larrauri et al., 1997). Determination of phenol content was performed according to Folin-Ciocalteu method (Singleton et al., 1999), while flavonoid content determination was described in Pękal and Pyrzynska (2014). Pigments were extracted from 2 g of homogenized sample dissolved in 20 ml of acetone, briefly vortexed and centrifuged at 13,776×*g* (Centrifuge 5804R, Eppendorf, Germany), for 5 min. Chlorophyll a, b and carotenoid contents were analyzed spectrophotometrically (CINTRA 303, GBC, Australia), by measuring absorbance at 662, 645, and 470 nm, respectively, according to Costache et al. (2012). Acetone was used as blank.

TA.XT Plus Texture Analyzer (Stable Micro Systems, England, UK) with Texture Exponent Software TEE32 (Version 6,0,6,0, Stable Micro Systems, England, UK) was used for measurement

of flesh firmness which is defined as the force (N) needed for penetration of 8 mm rounded probe into fruit flesh, with pre-set distance of 3 mm, at penetration speed of 10 mm $s^{-1}$ and trigger force 25 g (Stanley et al., 2013). Measurement was performed on 10 randomly chosen fruit. Before the analysis, a small circle of skin was removed from each apricot at its equatorial region with a sharp peeler.

Fruit skin color was measured by CR-400 Chroma Meter (Konica-Minolta, Osaka, Japan) on 10 randomly selected apricot fruit. Color difference ($\Delta E$) of differently treated fruits (*tf*) in comparison to fully ripe fresh apricot fruit (*fff*) was calculated according to the formula:

$$\Delta E = \sqrt{\left(L^*_{fff} - L^*_{tf}\right)^2 + \left(a^*_{fff} - a^*_{tf}\right)^2 + \left(b^*_{fff} - b^*_{tf}\right)^2}$$

Sugar and organic acid contents were determined by high-performance liquid chromatography (HPLC) (Agilent 1200 series, Agilent, USA), according to Milenković et al. (2020). Sugar content was examined using Agilent, Zorbax Carbohydrate 4.6 × 250 mm, 5 μm column (Agilent Technologies), evaporative light scattering detector (ELSD), while organic acid content was examined using NUCLEOGEL SUGAR 810 H (MACHEREY-NAGEL) column with diode array detector (DAD).

Sensory profiling analysis (Keenan et al., 2012) was performed on apricots after storage. Panel of eight members with previous sensory experience and thorough knowledge about apricot fruit quality and properties consisted of four males and four females within age span from 25 to 55 years trained according to the guidelines set out in ISO 8586:2012 and ISO 6564:1985 and tested using a series of acuity and discrimination tests (ISO 8586:2012). The main descriptors characterizing appearance, flavor and mouthfeel encompassing taste, flavor, textural attributes and quality deficiencies of apricot were selected during the training session. A total of eight descriptors were developed and agreed upon by panel consensus: sweetness, sourness, apricot aroma, nonspecific taste, crispiness, gumminess, tissue softening and browning. Sensory profiling was carried out in a sensory laboratory with individual testing booths equipped with serving windows and controlled lighting in Institute of food technology in Novi Sad, Serbia. For assessment of sweetness, sourness, apricot aroma, nonspecific taste, crispiness, gumminess the panelists were presented with samples of sliced apricot fruits using a completely randomized sample presentation. Intensity ratings for each of the descriptive terms were scored using a 10 cm line scale ranging from low (0 cm) to high intensity (10 cm). In a pre-test session, the panel members were calibrated using samples that were considered most different for each of the selected sensory descriptors typical for apricot (Johansen et al., 2010). Values of assessed descriptors (0–100) were obtained by measuring distance (mm) from the zero point on 10 cm line scale for each panelist. For assessment of tissue softening panelists were presented with 20 halved apricot fruits. The degree of tissue softening and browning was assessed for each individual half in % of total area of halved fruit.

Analyses of the total count of yeasts and molds in samples were performed according to ISO 21527-1:2008 standard.

Obtained data were statistically analyzed using software Statistica (TIBCO Software Inc. 2018, version 13). Significance of differences was determined using one way ANOVA followed by Duncan's multiple range test, while multivariate explanatory analysis was performed using principal component analysis (PCA).

## 3 | RESULTS AND DISCUSSION

### 3.1 | Respiration rate and ethylene production

Fruit harvested in the stage of commercial ripeness exhibited more intensive and increasing respiration (Figure 1a) and ethylene production (Figure 1b) in comparison to fully ripe fruit (Figures 1c,d). After 21 days of storage, respiration rate and ethylene production in commercially ripe fruit increased additionally and during the shelf life exhibited even more sharp increase. Ethylene production peak of commercially ripe fruit at harvest was recorded after 6 days of shelf life, while in the fruit stored for 21 days, the peak was recorded after 4 days of shelf life and was even higher than in fresh fruit (Figure 1b). Increasing pattern of respiration rate of fully ripe fruit after harvest was much less expressed than in commercially ripe fruit. After 21 days of cold storage, respiration rate regardless of applied $CO_2$ treatment increased slightly but the differences among treatments were not significant. Pérez-Pastor et al. (2007) also detected increase of $CO_2$ production in apricot fruit after cold storage.

Ethylene production of harvested fully ripe fruit (Figure 1d) was very low and it did not change significantly over the time, that is, no ethylene peak was recorded. Ethylene production rate of fully ripe fruit after 21 days of storage increased slightly regardless of applied $CO_2$ treatment, but the differences among treatments and in comparison to the fresh fruit were not significant. Appearance of ethylene peak in harvested apricot fruit depend on fruit maturity (Fan et al., 2018), storage temperature (Álvarez-Hernández et al., 2020) and cultivar (Cui et al., 2019). Apricot, as climacteric fruit, could produce ethylene peak after cold storage, but appearance of the peak depends on storage length and cultivar (Valdes et al., 2009). Similar to our results for commercially ripe fruit, apricot (cv. "Aprikoz") after 20 days of storage and 2 days on room temperature, packed in HDPE MAP significantly increased ethylene production (Koyuncu et al., 2010).

### 3.2 | Water and total soluble solids contents

In commercially ripe fruit, water content (WC) is higher and total soluble solids (TSS) content is lower in comparison to fully ripe fruit (Figure 2a,b), but changes of both parameters, WC decrease and TSS increase are less expressed in the case of commercially ripe fruit.

However, in both cases when fully ripe fruits were packed ($CO_2$-100% and MAP), WC and TSS did not change significantly in comparison

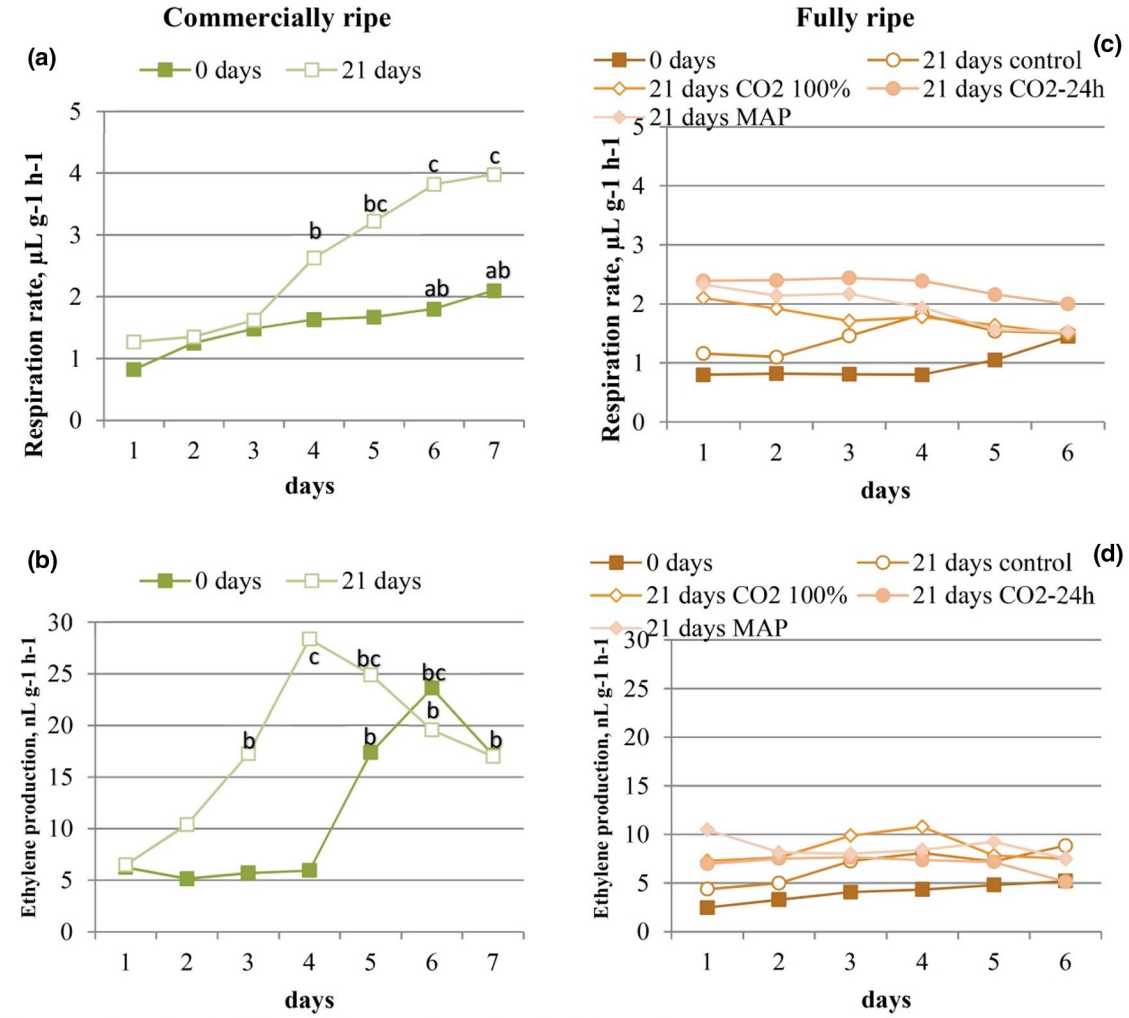


FIGURE 1 Respiration and ethylene production rate in dependence of apricot ripening stage and postharvest treatment

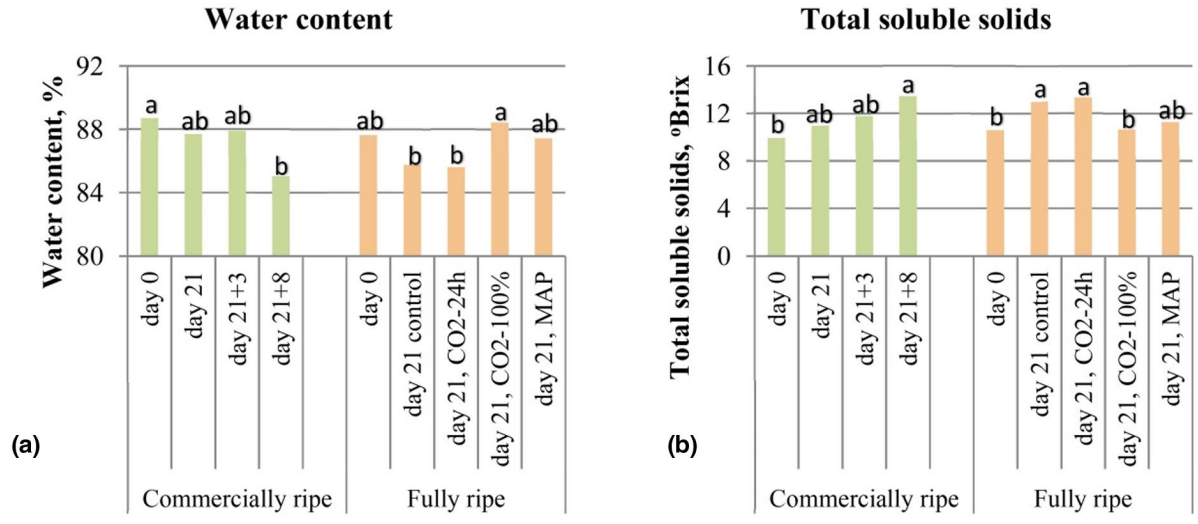


FIGURE 2 Water content and total soluble solids in dependence of apricot ripening stage and postharvest treatment

to freshly harvested fruits. It is well known that storage temperature affect strongly TSS level. For example, significantly higher TSS content increase was recorded at 8°C compared to 1°C, for all investigated cultivars (Medina-Santamarina et al., 2021), while Antunes et al. (2003) reported cultivar-dependent changes of TSS at 3°C for 19 days.

### 3.3 | Fruit composition

Commercially ripe apricots were characterized with significantly lower sucrose content in comparison to fully ripe fruit (Table 1). In apricots harvested in commercial ripening stage further increase of sucrose content did not occur, but fructose content increased over the cold storage period and initial stages of shelf life. Increase of sucrose content and decrease of fructose content were recorded only in late stages of shelf life in commercially ripe fruit (21 + 8 days). Determined changes in sugars content during postharvest ripening of commercially ripe apricot fruit are obviously not following the path of sugar synthesis during natural ripening of apricot. According to Bureau et al. (2001), during natural ripening of apricot, glucose levels remains at the same level during fruit ripening, while sucrose and fructose levels increase permanently during ripening.

Sucrose content decreased also during cold storage of unpacked fully ripe fruit. In packed fruit sucrose content did not change significantly in the case of MAP, but $CO_2$-100% induced increase in sucrose content. Fructose content increased significantly during cold storage of fully ripe fruits regardless of applied treatment, while glucose content was at similar level regardless of ripening stage and $CO_2$ treatment during storage of fully ripe fruit.

In commercially ripe apricot fruit cold storage did not affect significant changes in organic acids content and composition, but during the shelf life the content of citric and succinic acids significantly increased (Table 1). In fully ripe fruit regardless of applied packaging treatment, except slight increase of malic acid content, no significant changes in acids composition and content were noted. Synthesis of citric and malic acid during natural ripening of apricot fruits is cultivar dependent, but generally acids content increase until certain, cultivar dependent moment, and afterward decreases (Bureau et al., 2001).

Total phenols (TP) and flavonoids (TF) content (Table 1) increased during 21 day of cold storage in both, commercially and fully ripe fruit. When fully ripe fruit were exposed to any of applied $CO_2$ treatments the increase of analyzed antioxidants did not occur. According to Medina-Santamarina et al. (2021) TP content depends on cultivar and temperature during storage with an increase during cold storage followed by the decrease in the case of certain cultivars.

Carotenoid content (Table 1) in commercially ripe apricots increased significantly during storage at low temperature and the increase continued during shelf life at room temperature, reaching significantly higher level than in fully ripe apricot after 21-day of cold storage, regardless of applied packaging treatment. In fully ripe fruit carotenoid content increased slightly in fruit stored without packaging, with more expressed increase when no treatment with $CO_2$ was applied. In packaged fruit carotenoid content did not change significantly, it even decreased slightly when fruits were packed in $CO_2$-100%.

### 3.4 | Fruit skin color

There were no significant difference between fully and commercially ripe apricots in fruit skin lightness ($L^*$) after the harvest, but with exemption of MAP packed fruit, cold storage of apricots resulted in the reduction of lightness, with more expressed reduction of fruit lightness in the case of commercially ripe fruit (Table 2). Decreasing trend of fruit skin lightness was even more expressed during shelf life of commercially ripe fruits at room temperature, while fully ripe fruits were less susceptible to lightness reduction.

Fully ripe apricot had significantly more expressed red tone ($a^*$) and somewhat less expressed yellow tone ($b^*$) (Table 2). During cold storage red tone of commercially ripe apricots increased to the level characterizing fully ripe apricots while the intensity of red tone of

**TABLE 1** Sugars, acids, and bioactive compounds profile of apricots in dependence of apricot ripening stage and postharvest treatment

| Ripeness | Storage (treatment) | Fructose | Glucose | Sucrose | Malic | Citric | Succinic | Total phenols | Total flavonoids | Carotenoids |
|---|---|---|---|---|---|---|---|---|---|---|
| | | g/100 g FW | | | | | | mg/100 g FW | | |
| Commercial | 0 | $1.10^{a}$ | $0.85^{a}$ | $5.57^{b}$ | $1.68^{b}$ | $1.98^{c}$ | $0.63^{ab}$ | $44.7^{a}$ | $7.60^{c}$ | $1.48^{a}$ |
| | 21 days | $1.50^{c}$ | $0.89^{a}$ | $4.64^{a}$ | $1.58^{a}$ | $1.95^{c}$ | $0.65^{ab}$ | $54.7^{b}$ | $8.11^{d}$ | $2.86^{bc}$ |
| | 21 + 3 | $1.51^{c}$ | $0.90^{a}$ | $4.36^{a}$ | $1.64^{ab}$ | $2.14^{d}$ | $0.97^{c}$ | $49.1^{ab}$ | $5.62^{a}$ | $3.21^{c}$ |
| | 21 + 8 | $1.44^{bc}$ | $0.91^{a}$ | $5.81^{b}$ | $1.80^{c}$ | $2.13^{d}$ | $1.29^{d}$ | 57.0 | 6.52 | $5.80^{d}$ |
| Full | 0 | $1.18^{ab}$ | $0.88^{a}$ | $6.32^{c}$ | $1.68^{b}$ | $1.61^{b}$ | $0.53^{a}$ | $43.3^{a}$ | $5.69^{a}$ | $2.43^{b}$ |
| | 21 (control) | $1.38^{b}$ | $0.80^{a}$ | $5.91^{b}$ | $1.80^{c}$ | $1.55^{b}$ | $0.60^{ab}$ | $48.0^{ab}$ | $6.75^{bc}$ | $2.70^{b}$ |
| | 21 ($CO_2$-24 hr) | $1.36^{b}$ | $0.85^{a}$ | $5.60^{b}$ | $1.62^{ab}$ | $1.39^{a}$ | $0.97^{c}$ | $41.8^{a}$ | $6.19^{b}$ | $3.18^{c}$ |
| | 21 ($CO_2$-100%) | $1.45^{bc}$ | $0.90^{a}$ | $6.83^{c}$ | $1.89^{d}$ | $1.54^{b}$ | $0.64^{ab}$ | $42.5^{a}$ | $5.96^{ab}$ | $2.22^{b}$ |
| | 21 (MAP) | $1.42^{bc}$ | $0.90^{a}$ | $6.25^{bc}$ | $1.79^{c}$ | $1.57^{b}$ | $0.72^{b}$ | $40.9^{a}$ | $5.90^{ab}$ | $2.58^{b}$ |

*Note*: Statistically significant values are denoted with different letters.
Abbreviation: FW, fresh weight.

TABLE 2 CIElab color properties of apricots in dependence of apricot ripening stage and postharvest treatment

| Ripeness | Storage (treatment) | $L^*$ | $a^*$ | $b^*$ | $\Delta E$ from ripe fresh apricot |
|---|---|---|---|---|---|
| Commercial | 0 | $60.49^{d}$ | $13.77^{a}$ | $38.59^{ab}$ | $6.12^{A}$ |
| | 21 days | $60.40^{d}$ | $19.31^{bc}$ | $41.2^{b}$ | $9.72^{A}$ |
| | 21 + 3 | $56.46^{bc}$ | $22.49^{c}$ | $29.72^{a}$ | $12.55^{B}$ |
| | 21 + 8 | $52.00^{a}$ | $19.88^{bc}$ | $30.72^{a}$ | $13.44^{B}$ |
| Full | 0 | $54.78^{a}$ | $18.57^{bc}$ | $36.94^{ab}$ | 0.00 |
| | 21 (control) | $58.30^{c}$ | $21.22^{c}$ | $31.9^{a}$ | $7.09^{A}$ |
| | 21 ($CO_2$-24 hr) | $58.71^{cd}$ | $17.80^{b}$ | $33.4^{a}$ | $8.12^{A}$ |
| | 21 ($CO_2$-100%) | $59.73^{cd}$ | $19.50^{bc}$ | $33.8^{a}$ | $7.44^{A}$ |
| | 21 (MAP) | $61.90^{e}$ | $20.21^{c}$ | $33.5^{a}$ | $7.90^{A}$ |

*Note*: Statistically significant values are denoted with different letters.
[A]Apparently different colors.
[B]colors of different shade.

fully ripe apricots, regardless of applied treatment did not change significantly. The intensity of yellow tone decreased during storage regardless of ripening stage and during the shelf life of commercially ripe apricots increased again (Table 2).

Oppositely to our findings, Moradinezhad and Dorostkar (2021) reported an increase in $L^*$, but no change in $a^*$ and $b^*$ in packed commercially ripe apricot fruits in high $CO_2$, but also in $O_2$ and $N_2$ atmosphere during storage at 2°C, pointing out that these changes might be cultivar dependent. In investigations reported by Ayhan et al. (2009), internal and external lightness $L^*$, as well as $a^*$ and $b^*$, of apricot fruit also showed stability during first 28 day of cold storage. The stability of external color of the same cultivar of apricot, expressed as chroma (C*) and hue angle (H°) during 28 days of cold storage was also demonstrated by Muftuoğlu et al. (2012). However, internal color expressed as C* increased from day 14 until day 28, while h° did not change. Koyuncu et al. (2010) reported fluctuation in $L^*$ and $a^*$ suggesting that color could be cultivar depended. Changes in apricot fruit $L^*$, $a^*$ and $b^*$ depend also on maturity and storage temperature (Fan et al., 2018).

Color difference ($\Delta E^*$) indicating the degree to which colors of apricots stored under investigated conditions and fresh fully ripe apricot differentiate, was calculated (Table 2). The lowest color differences were noted in the case of packed fully ripe fruit. In the case of commercially ripe fruit difference of color were much higher. According to Kim et al. (2002) and Kevrešan et al. (2013) values of $\Delta E^*$ in the range from 6.0 to 12.0 indicate existence of apparent difference in color, while values above 12.0 indicate color of a different shade, meaning that regardless of applied treatment the difference in color of fruit delivered to consumers after 21 days will be apparently different from freshly harvested fully ripe fruit, while commercially ripe apricots after storage will provide a color of different shade implicating a different impression to the consumers.

## 3.5 | Fruit flesh firmness

One of the most important properties of apricot fruit is flesh firmness which changes during fruit ripening through the processes of natural degradation of tissue structure (Infante et al., 2008), transforming very firm fruit to appealingly soft and further, to unacceptably degraded. Flesh firmness of commercially ripe fruit is multiply higher than flesh firmness of fully ripe fruit (Figure 3). During 21 days of storage flesh firmness of commercially ripe apricot decreases under the level of fresh fully ripe fruit firmness. During shelf life at room temperature flesh firmness of commercially ripe fruit decreases rapidly resulting in very soft fruit tissue. Reduction of fruit firmness of fully ripe fruits during 21 days of cold storage was much less expressed and the degree of firmness reduction depended on applied $CO_2$ treatment (Figure 3). Storage without packaging regardless of treatment with $CO_2$ for 24 hr resulted in the most expressed reduction of fruit firmness, while packaging in $CO_2$-100%, and particularly in MAP resulted in a less expressed reduction of fruit firmness (Figure 3).

Influence of packaging solution on the loss of fruit firmness was also reported by other authors. Moradinezhad and Jahani (2019) reported that apricot fruit wrapped in cellophane lost more firmness than unpacked fruit, while Moradinezhad and Dorostkar (2021) state that after six weeks of storage in high $CO_2$ atmosphere at 2°C, apricot fruit lost significantly less firmness than control, unpacked fruit. Onursal et al. (2013) reported that fruit firmness of apricot was better preserved when, besides packing in MAP, it was treated with putrescine. During storage, apricot firmness depends on packaging material including its type and thickness (Peano et al., 2014), but reaction to packaging material is cultivar depended (Kuzucu & Önder, 2010). Not all treatments applied to apricot fruit preserve fruit firmness. On the contrary, beta ionization (Egea et al., 2007) and naphthalene acetic acid (Mesa et al., 2012) reduced flesh firmness.

## 3.6 | Sensory properties

During storage, sensory properties of apricot including its appearance texture, taste, aroma but also appearance of quality deficiencies change significantly.

Results of sensory analysis of texture related parameters (Table 3) confirm that during shelf life commercially ripe apricot

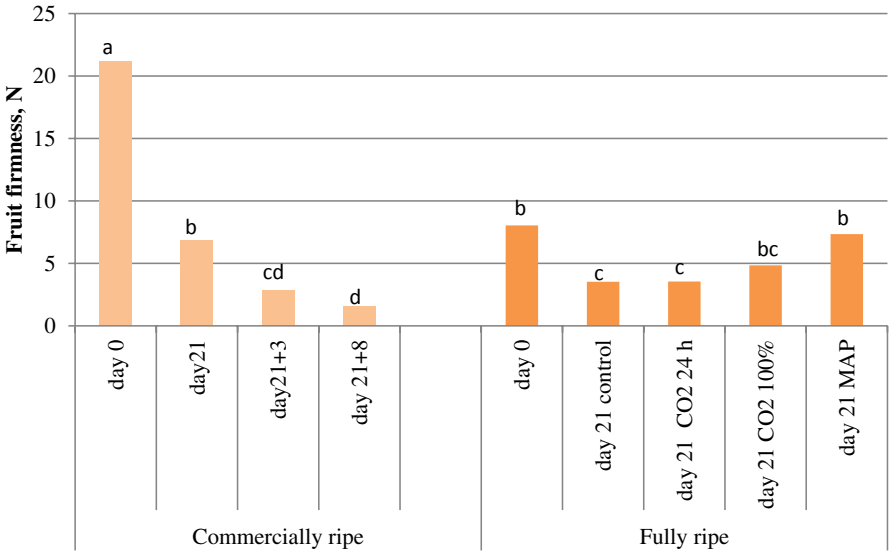


**FIGURE 3** Flesh firmness of apricots in dependence of apricot ripening stage and postharvest treatment

**TABLE 3** Sensory profile of apricots in dependence of apricot ripening stage and postharvest treatment

| Ripeness | Storage (treatment) | Tissue softening | Crispiness | Gumminess | Sweetness | Acidity | Apricot aroma | Browning | Inappropriate taste |
|---|---|---|---|---|---|---|---|---|---|
| Commercial | 21 days | $0^{a}$ | $30.5^{a}$ | $47.5^{a}$ | $41.2^{ab}$ | $29.8^{a}$ | $47.0^{b}$ | $0^{a}$ | $0^{a}$ |
| | 21 + 3 | $9^{b}$ | $0.3^{b}$ | $10.6^{c}$ | $56.8^{a}$ | $22.8^{ab}$ | $66.5^{a}$ | $2^{a}$ | $0^{a}$ |
| | 21 + 8 | $52^{d}$ | $4.8^{b}$ | $8.7^{c}$ | $58.7^{a}$ | $15.0^{b}$ | $66.0^{a}$ | $3^{a}$ | $3.0^{a}$ |
| Full | 21 (control) | $58^{d}$ | $27.6^{a}$ | $22.6^{b}$ | $45.8^{ab}$ | $10.8^{b}$ | $61.0^{a}$ | $16^{ab}$ | $9.8^{a}$ |
| | 21 ($CO_2$-24 hr) | $52^{d}$ | $23.4^{a}$ | $20.4^{b}$ | $36.2^{b}$ | $11.8^{b}$ | $64.8^{a}$ | $49^{b}$ | $8.4^{a}$ |
| | 21 ($CO_2$-100%) | $50^{d}$ | $30.6^{a}$ | $26.0^{b}$ | $57.8^{a}$ | $13.2^{b}$ | $47.4^{b}$ | $29^{ab}$ | $12.6^{a}$ |
| | 21 (MAP) | $30^{c}$ | $33.4^{a}$ | $27.4^{b}$ | $40.0^{ab}$ | $22.4^{ab}$ | $53.8^{ab}$ | $18^{ab}$ | $6.2^{a}$ |

*Note*: Statistically significant values are denoted with different letters.

almost completely loses crispiness and gumminess and high level of tissue softening points out at intensive tissue structure degradation, particularly in later phases of fruit shelf life. Sensory analysis (Table 3) revealed also less expressed crispiness and gumminess of apricots in the case of fully ripe apricot stored without packaging. Apricot fruits were packed in $CO_2$-100%, and particularly in MAP demonstrated better assessment of crispiness and gumminess (Table 3) of fruit pointed out at less expressed loss of textural properties in the case of packed fruits. Fruit packed in MAP were characterized also with lower values for tissue softening (Table 3), indicating that fully ripe fruit tissue degradation was less expressed when this packaging solution was applied.

Fully ripe fruit, according to sensory assessment of sweetness (Table 3), were sweeter after cold storage than commercially ripe fruits after the same period of cold storage, but the sweetness of commercially ripe fruit during shelf life exceeded sweetness of fully ripe fruit, most probably due to a higher content of fructose, as sugar with more intensive sweetness (Mahawanich & Schmidt, 2004). Sensory assessment of acidity of apricot fruit (Table 3) revealed preservation of more intensive acidity in commercially ripe apricots during cold storage and in initial phase of shelf life. In fully ripe fruits higher acidity level was preserved only in apricots stored in MAP. Although there were no statistically significant differences in apricot aroma, somewhat lower level of aroma was registered in packed apricots in comparison to unpacked fruits regardless of ripening stage (Table 3).

The intensity of appearance of quality deficiencies (Table 3) showed more intensive browning in fully ripe apricots, with significantly more expressed intensity of this deficiency only in the case of apricots treated with $CO_2$ for 24 hr and afterwards stored unpacked. Fruit ripening stage seems to be the main factor in browning development. It has already been confirmed (Watkins, 2000) that the development of browning in apricot fruit is $CO_2$ sensitive. Concentrations above 5% are considered to cause injury, but if the $CO_2$ concentration is kept at the 4% level, apricots develop less browning when compared to fruits packed in MAP atmosphere, covered with film and control fruit (Koyuncu et al., 2010). However, if $CO_2$ level is kept at 2.5% level less decay is observed in fruits kept in MAP bags than at 2.5% $CO_2$ (Gabioud Rebeaud et al., 2013), which confirms high sensitivity of apricot fruit regarding browning on $CO_2$ concentration.

Inappropriate taste (Table 3) had the highest intensity in apricots stored in 100% $CO_2$ but the difference of intensity of inappropriate test was among applied treatments not statistically significant.

**TABLE 4** Yeast and mold count of apricots in dependence of postharvest treatment

| Treatment | Yeast count, log CFU | Mold count, log CFU |
|---|---|---|
| Without packaging | 3.02[b] | 2.30[b] |
| Without packaging, exposed to $CO_2$ 100% 24 hr | 2.40[b] | 2.54[b] |
| Packed MAP, commercial MAP bags | 2.88[b] | 2.85[b] |
| Packed, in 100% $CO_2$ | 0[a] | 1.54[a] |

*Note*: Statistically significant values are denoted with different letters.

## 3.7 | Microbial count

For the purpose of safety aspect, an estimation of total count of yeasts and molds was determined (Table 4). Both, yeast and mold count were the highest in the case of non-treated, non-packaged apricot samples, while packaging in controlled 100% atmosphere suppressed completely yeast growth and significantly reduced mold growth. Yeast count was lower also in samples treated with $CO_2$-24 hr and samples packed in MAP while these treatments increased mold growth. However, both mold and yeast counts in the case of all treatment stayed within expected limits for apricot (Gull et al., 2021) which doesn't impose significant safety risks.

## 3.8 | Ripening stage versus postharvest ripening changes

Principal component analysis was performed separately for color, texture, taste and indicators of postharvest metabolic activities (Figures 4a–d, respectively). In the case of color and texture properties (Figure 4a) position of apricot samples in factorial plane

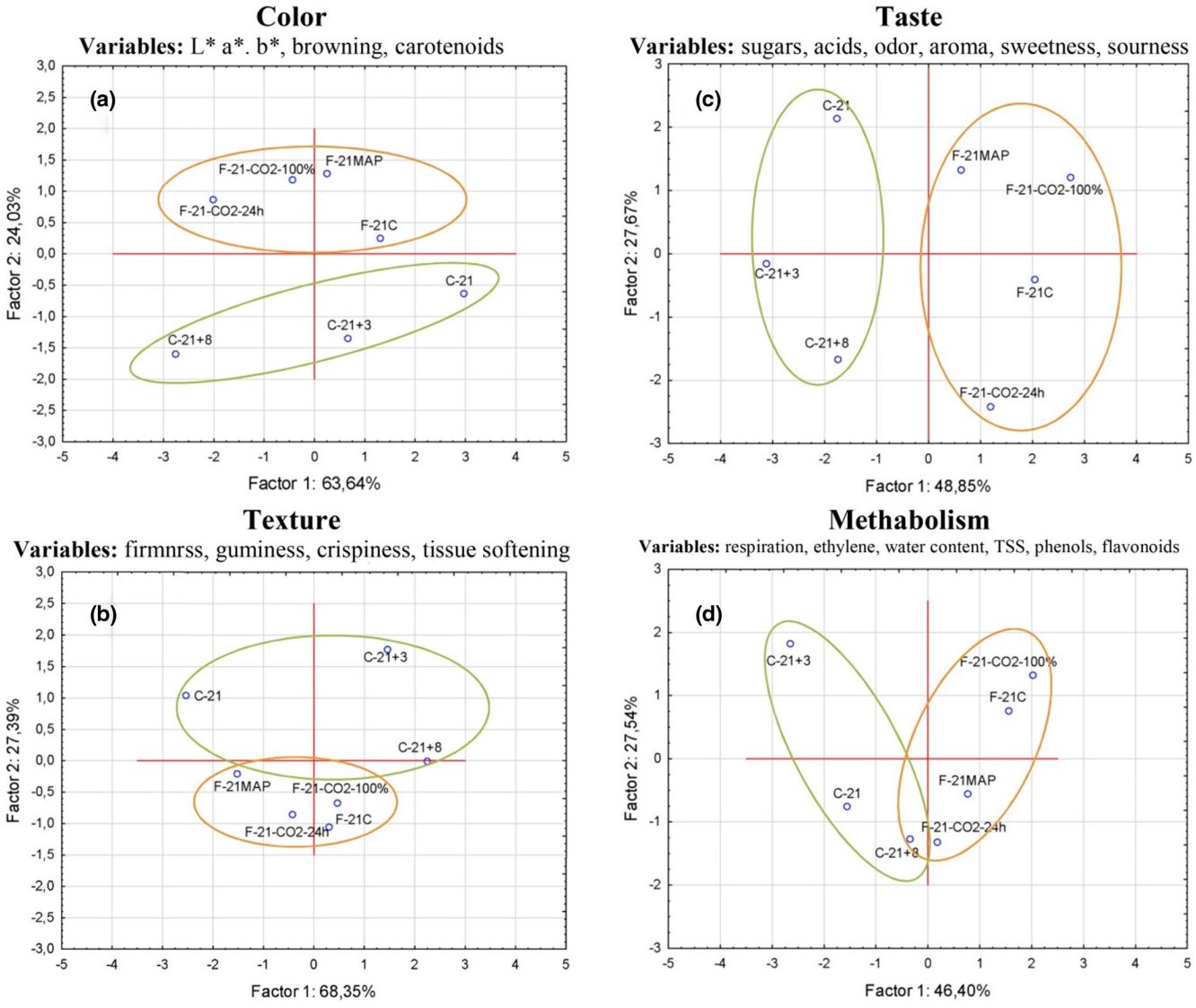


**FIGURE 4** Principal component analysis

indicates that the main changes, related to the first principal component (63.4% and 68.35% of variability, respectively), are the changes of color and texture of commercially ripe apricots during the postharvest ripening process. On the basis of the second principal component (24.03% and 27.39% of variability, respectively), clear differentiation between apricots harvested in fully ripe and commercially ripe stage can be noted regardless of the duration of ripening of commercially ripe apricots and applied treatment of fully ripe apricots.

In the case of apricot taste (Figure 4c) as well as in the case of indicators of metabolic activities (Figure 4d), based on the first principal component (48.85% and 46.40% variability, respectively), clear differentiation between commercially ripe and fully ripe apricots can be noted. In the case of taste and metabolic activities related properties based on the second principal component (27.67% and 27.54%, variability, respectively), the differentiation of commercially ripe apricots ripening during shelf life, as well as differentiation among fully ripe apricots stored under different regimes can be noted. Principal component analysis indicates that, based on all factors relevant for consumers (taste, color, and texture), but also in the case of fruit metabolic activities the differences between fully ripe and commercially ripe apricots in the moment of their delivery to consumers, are clearly identifiable. The second observation from the principal component analysis is that applied treatment in terms of packaging and $CO_2$ treatment, resulted in significant differences of fully ripe apricots, but these differences are minor in comparison to the changes of properties of commercially ripe apricot during the shelf life.

## 4 | CONCLUSION

Due to the short shelf life of fully ripe fruit, apricots are, for the purpose of distribution on the market, harvested in premature stage and ripened during the delivery process. Ripening processes are suppressed during the period of cold storage of apricots and intensified during the shelf life, with high respiration rate and ethylene production, leading to fast degradation of fruit properties to the level bellow acceptability for the consumers, particularly in the case of loss of firm and crispy texture, extensive tissue softening and loss of fruit lightness. Harvesting of fully ripe apricot fruit and their delivery to consumers as ready to eat, through the cold chain in combination with suppression of quality deterioration by packaging enabling equilibrium level of $CO_2$ content due to fruit respiration process (MAP) seems to be an acceptable alternative for marketing of fresh apricots. However, browning of fully ripe apricot fruits might represent the problem which deserves additional research in terms of optimization of $CO_2$ concentration which will result in suppression of this negative effect, as well as determination of maximal duration of storage during which browning will not exceed acceptable levels. This may provide the consumers an opportunity to consume apricot with quality properties much closer to the properties of fresh harvested fully ripe fruit.

### AUTHOR CONTRIBUTIONS

**Jasna Mastilović:** Conceptualization; data curation; supervision; writing – original draft. **Žarko Kevrešan:** Conceptualization; data curation; methodology; software; supervision; writing – original draft. **Maja Milović:** Formal analysis. **Renata Kovač:** Validation; writing – review and editing. **Biserka Milić:** Conceptualization. **Nenad Magazin:** Conceptualization. **Dragana Plavsić:** Formal analysis; methodology. **Jelena Kalajdzić:** Formal analysis.

### CONFLICTS OF INTEREST

The authors declare no conflict of interest.

### DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

### ORCID

*Renata Kovač* https://orcid.org/0000-0002-9600-537X

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