TITLE: IAD values of apricot (Prunus armeniaca L.) at harvest in relation to fruit quality and sensory properties during cold storage and shelf life

AUTHORS: Kovač, R., Kevrešan, Ž., Mastilović, J., Magazin, N., Milić, B., Milović, M., Bajić, A., Kalajdžić, J., Barać, G. and Keserović, Z.,

This article is provided by author(s) and FINS Repository in accordance with publisher policies.

The correct citation is available in the FINS Repository record for this article.

NOTICE: This is the author's version of a work that was accepted for publication in *New Zealand Journal of Crop and Horticultural Science.* Changes resulting from the publishing process, such as peer review, editing, corrections, structural formatting, and other quality control mechanisms may not be reflected in this document. Changes may have been made to this work since it was submitted for publication. A definitive version was subsequently published in *New Zealand Journal of Crop and Horticultural Science*, Volume 50, issue 2-3, 2022, Pages 205–222. DOI: 1 0.1080/01140671.2022.2067189

This item is made available to you under the Creative Commons Attribution-NonCommercial-NoDerivative International – CC BY-NC-ND 4.0

I_{AD} values of apricot (*Prunus armeniaca* L.) at harvest in relation to fruit quality and sensory properties during cold storage and shelf life

DA-meter enables quick and non-invasive determination of fruit ripeness in different types of fruit, including apricots. In order to examine the postharvest physiology of apricots, fruits were divided into five I_{AD} categories (0.00; 0.01−0.40; 0.41−0.80; 0.81−1.20; and >1.20) and were analyzed in terms of the physicochemical and sensory properties at harvest, after 21 days of cold storage and after 3 days of shelf life. The specified I_{AD} categories differed in terms of ethylene production, flesh firmness, skin color, composition and sensory properties at harvest. After cold storage and shelf life, ethylene production and respiration patterns, sensory properties, color, and fruit composition were affected by the I_{AD} value. Fruit assigned to the categories I_{AD} 0.81−1.20 and I_{AD} > 1.20 categories maintained higher firmness compared with the remaining three groups. Carotenoid, phenol, fructose, sucrose, citric and succinic acid content were affected by the I_{AD} value during storage. Apricots attained optimal properties for consumption in different postharvest periods, depending on their maturity stage. These findings suggest that I_{AD}-based segregation can support apricot fruit management during storage and shelf life.

Keywords: *Prunus armeniaca*, I_{AD} value, cold storage, shelf life, postharvest

ACCEPTED VERSION

Introduction

Apricots (*Prunus armeniaca* L.) are not only endowed with specific flavor and appealing sensory properties but are also rich in bioactive phytochemicals (phenols, carotenoids), vitamins, fibers and minerals (Leccese *et al.*, 2007; Vardi *et al*., 2008) and are thus good addition to a healthy diet, especially when consumed in fresh form (Ayour *et al.*, 2017).

The sensory properties sought by the consumers are achieved in the final ripening stage, during which the breakdown of flesh tissue occurs, resulting in a transformation from firm, quite tasteless and sour to tasty, aromatic, sweet and soft fruit. However, fully ripe apricots are characterized with short storability and shelf life, as they spoil easily and are prone to mechanical injury. Consequently, the period from commercial ripening to degradation is very short, limiting the availability of fresh apricots for consumers (Ezzat, 2019). Majority of apricot varieties ripen at an uneven rate, requiring trained workforce for harvesting fruits in the same ripening stage, and extending the harvest over a considerable period. On the other hand, harvesting of apricots in different ripening stages

results in different postharvest physiology of fruit, which causes heterogeneity in not only quality but also properties related to storage, shelf life and consumption.

Segregating apricot fruit by ripening stages at harvest prior to storage expedites the harvest process, put necessitates postharvest management, depending on the ripening stage in which fruits were harvested. Segregation of fruits according to ripeness at harvest, or before storage, can be based on fruit color (Fan *et al.*, 2000; Bartolini *et al.*, 2006; Infante *et al*., 2008; Defilippi *et al*., 2009; Stanley *et al.*, 2013), or flesh firmness and total soluble solids (TSS) (Fan *et al.*, 2018a). It can also be based on the number of days after full bloom (Ezzat, 2019), or empirically determined visual and tactile properties (Campbell *et al.*, 2013). However, application of empirical methods requires experience and has a number of drawbacks, as the color does not always reflect fruit maturity, whereas some methods such as TSS measurement are destructive. Hence, classification of apricot fruit on the basis of maturity is a challenging task.

Recently, several non-destructive approaches for fast and reliable determination of fruit maturity have been developed (Vanoli and Buccheri, 2012). One such strategy relies on the determination of I_{AD} value using a hand-held DA-meter, or a line-integrated instrument (Costa *et al.*, 2017). Functioning of DA-meter is based on visible/near infrared (vis/NIR) spectroscopy, whereby absorbance at a wavelength specific to a particular fruit type is used to calculate the absorbance difference (I_{AD}) (Ziosi *et al.*, 2008; Doerflinger *et al.*, 2016). The I_{AD} value correlates to the actual content of chlorophyll in flesh and ethylene production to a greater extent than to other physical and chemical parameters commonly used to describe the fruit maturation process (Ziosi *et al.*, 2008; Costa *et al.*, 2009). Moreover, Zhang *et al*. (2019) established a positive correlation between I_{AD} and firmness in five peach cultivars. Sadar *et al.* (2019) similarly reported a strong inverse relationship between I_{AD} and fruit ethylene production, indicating that DA-meter as a reliable tool for evaluating fruit maturity. Guided by this evidence, commercial fruit producers are increasingly using DA-meter, indicating the need for a more detailed research regarding the quality and sensory properties of fruits in relation to the I_{AD} value not only at harvest but also in the postharvest period.

Changes in apricot properties during ripening are subject of extensive research involving different segregation methods, yielding two (Ayour *et al*., 2016), three (Dragovic-Uzelac *et al*., 2007; Hegedüs *et al*., 2011; D'Ambrosio *et al*., 2013; Ayour *et al*., 2017; Iordanescu

ACCEPTED VERSION

et al., 2018), four (Bae *et al*., 2014), five (Németh *et al*., 2011), six, seven (Durmaz *et al*., 2010) or even twelve (Bureau *et al*., 2009) maturity stages.

For example, Costa *et al*. (2018) classified cv. "Swingold" apricot into four I_{AD} categories (0−0.5, 0.5−0.7, 0.7−0.9 and 0.9−2.0) which were not visually distinct, but differed in the TSS content (14.9%, 14.2%, 13.2% and 12.5%, respectively) that was assumed to correspond to the postharvest fruit physiology classes. However, contrary to the abundance of studies focusing on the changes in apricot fruit in relation to the maturity stage, those examining the effect of maturity stage on the postharvest physiology of apricots are limited. Authors of the few available studies typically consider three maturity stages (Infante *et al*., 2008; Stanley *et al*., 2013; Ezzat, 2019) and rely on empirical or destructive methods for fruit segregation. Therefore, further investigations based on rapid sensor-based determination of fruit maturity stage are needed, as this permits delineation of a greater number of maturity groups, and is justified from the aspect of fruit postharvest properties. Sill, studies in which DA-meter was used for fruit segregation prior to storage are quite rare. For example, only Spadoni *et al*. (2016) segregated peaches into two maturity stages using DA-meter in order to study postharvest physiology after cold storage, while the same method has never been used for assessing the postharvest physiology of formed lots.

This gap in extant research has motivated the present study, as a part of which five apricot maturity groups were formed based on I_{AD} values with the view of supporting better fruit management during 21-day storage and 3-day shelf life.

Material and methods

Apricot fruit production and sampling

Apricots (*Prunus armeniaca* L.) cultivar "NS4" were produced at the Experimental field for fruit growing, Faculty of Agriculture, Novi Sad, located at Rimski Šančevi (45˚3382' N and 19˚8445 ' E, 86 m a.s.l.), Republic of Serbia. According to the authors' experience and nonpublished results, in the stage of commercial ripeness, cv. "NS4" chosen for this investigation is distinguished by bright orange color with slight red tones. When compared to the other varieties grown in Serbia, cv. "NS4" is characterized by medium firmness and quite low weight loss during cold storage. Moreover, it is not highly susceptible to chilling injuries, while it yields ethylene in high quantities during the

ACCEPTED VERSION

ripening process. For this investigation, fruits were harvested from ten representative trees of apricot cv. "NS4" and were classified into five I_{AD} categories determined by DA-meter (TR Turoni, Bologna, Italy): fully ripe I (I_{AD} = 0.00), ripe II (I_{AD} = 0.01−0.40), commercially ripe III (I_{AD} = 0.41−0.80), unripe IV (I_{AD} = 0.81−1.20) and completely unripe V (I_{AD} > 1.20) and were immediately transported to laboratory.

Collected fruit samples were analyzed at harvest, after 21-day cold storage (in wooden crates of 50 × 30 × 8 cm dimensions at 1 ± 1 °C) and after 3 days of shelf life at room temperature.

Ethylene production and respiration rate, fruit texture, color, and sensory analysis were performed 12 h following the harvest or cold storage in order for the fruit to reach constant room temperature. Composition analysis was carried out on average homogenized samples fast frozen in polyethylene bags, by placing them in thin layer on dry ice and storing at -18 °C until required for analysis.

Analytical methods

Weight loss was determined by measuring fruit weight for 6 consecutive days after the harvest and for 4 consequent days after cold storage at room temperature (24 ± 2 °C) and the results were expressed as a percentage (%) of the initial value.

Ethylene production and **respiration rate** (CO_2 production) were determined using approximately 250−300 g of fruit placed in a 770 ml container, hermetically sealed with multilayer foil for 4 h at 24 °C (± 2 °C). Ethylene content was analyzed using 2 ml of gas extracted from the container by plastic syringe and injected into 10 ml headspace vial sealed with silicone septa. Ethylene quantity was determined via gas chromatography apparatus (GC 7890, Agilent, USA), equipped with FID detector (Agilent, USA) and auto sampler (COMBIPAL, CTCAnalytics AG, Switzerland). Separation was performed on DB-WAX column using the method described by According Mandić *et al*. (2019), whereby temperature was increased from 60 °C to 150 °C, and flow rate was set to 30 mL/min, with nitrogen (N_2) as carrier gas, and split mode injection (10:1). CO_2 production was measured by directly puncturing the sealed foil with OXYBABY® 6.0 sampling needle (WIT-Gasetechnik GmbH & Co KG T, Germany). Production of CO_2 was determined from the difference in CO_2 concentration before sealing the dish and after 4

ACCEPTED VERSION

h. Finally, weight loss, ethylene and CO_2 production were determined on a daily basis for 6 consecutive days after the harvest and for 4 consequent days after cold storage.

Sensory evaluation of apricot fruit after cold storage and shelf life was conducted by 12 trained panelists (6 women and 6 men) aged 20−65 years, according to the methodology described by Melgarejo *et al.* (2014). The panelists were asked to score the visual appearance (tissue breakdown, pit burning, rotting) of halved fruits, and rate the intensity of five fruit attributes (sweetness, acidity, apricot flavor, crispiness and off flavor) by tasting fruit slices. Evaluation was performed on a continuous scale ranging from 0 to 10. The process was carried out at room temperature (20 °C) in individual cabins under white lighting, with each individual taking part in two sessions within the same day. All participants received written information about the study and provided signed informed consent.

Flesh firmness was examined on 20 randomly chosen apricot fruits using TA.XT Plus Texture Analyzer (Stable Micro Systems, England, UK). Small circle of skin was removed from each specimen at its equatorial region using a sharp peeler. Penetration test was performed at the opposite sides of the fruit specimen using rounded stainless steel cylinder probe of 8 mm diameter, while pre-set distance, penetration speed and trigger force were set to 3 mm, 10 mm s^{-1} and 25 g, respectively. Fruit firmness represents the force needed for penetration, expressed in Newton (N). Data were analyzed using Texture Exponent Software TEE32 (Version 6.0.6.0, Stable Micro Systems, England, UK) and the mean value of repeated measurements expressed in N (Stanley *et al*., 2013) was recorded.

Fruit color was determined in CIEL*a*b* color space using CR-400 Chroma Meter (Konica-Minolta, Osaka, Japan), whereby two measurements on the opposite sides of the equatorial region were performed on 10 randomly selected apricot fruit specimens.

Total soluble solids (TSS; %) were determined using digital refractometer ATR-ST plus (Schmidt + Haensch, Germany) on previously homogenized apricot samples at 20 °C.

Titratable acidity (TA, g malic acid/100 g) was measured in a 3 g sample dissolved in 30 ml of deionized water. After homogenization, the sample was centrifuged (Centrifuge 5804R, Ependorf, Germany) at 13.776 g for 5 min and 10 ml of supernatant was used for titration with 0.1M NaOH.

ACCEPTED VERSION

Phenols and flavonoids were extracted from 1 g of homogenized sample in two steps, according to Larrauri *et al*. (1997). Phenol content was established according to the Folin-Ciocalteu method (Singleton *et al.*, 1999), while flavonoid content was determined using the procedure described by Pękal and Pyrzynska (2014). Both parameters were determined using spectrophotometer CINTRA 303 (GBC, Australia). Phenols were expressed as mg of gallic acid equivalent (GAE) per 100 g fresh weight, while mg of quercetin equivalents (QE)/100 g of fresh weight was adopted for flavonoids.

Carotenoids were extracted from 2 g of homogenized sample dissolved in 20 mL of acetone, vortexed and centrifuged at 13,776xg (Centrifuge 5804R, Eppendorf, Germany) for 5 min. Carotenoid content (mg/100 g of fresh weight) was determined from undiluted extract by measuring absorbance at λ = 666, 653 and 470 nm using CINTRA 303 spectrophotometer (GBC, Australia), taking into account the molar extinction coefficient according to Costache *et al*. (2012).

Sugar and **organic acid compositions** were determined using high-performance liquid chromatography (HPLC) (Agilent 1200 series, Agilent, USA) according to Milenković *et al*. (2020). For this purpose, homogenized sample was dissolved in three-fold higher volume of demineralized water and centrifuged at 13,776xg (Centrifuge 5804R, Eppendorf, Germany) for 5 min. An aliquot from the obtained supernatant was diluted with two-fold higher volume of acetonitrile, filtered through 0.45-μm pore size filters and analyzed by HPLC. The HPLC parameters for sugar determination were as follows: Agilent, Zorbax Carbohydrate 4.6 × 250 mm, 5 μm column (Agilent Technologies), evaporative light scattering detector (ELSD), acetonitrile and water (75:25, v/v) solvent system at a flow rate of 1.1 mL min^{-1}, with total running time of 12 min and 10 μL injection volume. For organic acid composition, NUCLEOGEL SUGAR 810 H (MACHEREY-NAGEL) column with diode array detector (DAD), 5 mmol H_2SO_4 as a solvent with a flow rate of 0.6 mL min^{-1} at 65 °C were used. Total running time of 25 min and 5 μL injection volume were applied.

Statistical methods

Obtained results were analyzed using factorial ANOVA, with storage duration of (0, 21 and 21+3 days) and I_{AD}-based ripening stages (I_{AD} = 0.00; 0.01−0.40; 0.41−0.80; 0.81−1.20; and > 1.20) as factors. Duncan's multiple range test was conducted for assessing the significance of differences between average values, while Tukey's HSD test

ACCEPTED VERSION

was adopted for respiration and ethylene. All statistical calculations were performed using TIBCO Data Science − Workbench (Statistica® 14.0.0) (http://tibco.com).

Results and discussion

Typical ripening processes includes changes in the biochemical composition, structure and morphology of the fruit, resulting in softening, weight loss, yellowing and rotting (Brummell *et al.*, 2004; Goulao and Oliveira, 2008; Muzzaffar *et al.*, 2018). The findings yielded by the present study reveal differences in the postharvest ripening processes, sensory and physical characteristics, as well as chemical composition of apricots characterized by different I_{AD} values.

Ripening process

As shown in Figure 1, weight loss, respiration rate and ethylene production rate in fresh and stored apricots were monitored, as these parameters are considered reliable indicators of the fruit ripening process and depend on the ripening stage.

Insert Figure 1

According to the obtained results, fresh fruit (Figure 1A) exhibited greater losses relative to those measured after cold storage (Figure 1D), while somewhat higher losses were noted at the beginning of shelf life in fully ripe fruit (I_{AD} 0.00) compared to the remaining four ripening groups.

Respiration rate proved to be highly dependent on the ripening stage. At harvest, it was significantly higher in ripe (I_{AD} 0.01−0.40) and commercially ripe (I_{AD} 0.41−0.80) apricots after 4 and 6 days of shelf life when compared to the other three maturity groups (Figure 1B). Also at harvest, completely unripe apricots (I_{AD} > 1.20) exhibited significantly lower respiration rate than the remaining groups after 6 days of shelf life. Fruit subjected to cold storage conditions for 21 days exhibited a different respiration rate pattern in relation to the maturity stages (Figure 1E). After cold storage, the highest respiration rate was recorded on the last day of shelf life in completely unripe fruits (I_{AD} > 1.20), followed by unripe (I_{AD} 0.81−1.20) and commercially ripe (I_{AD} 0.41−0.80) apricots, while the lowest value was noted in the ripe (I_{AD} 0.01−0.40) and fully ripe fruits (I_{AD} 0.00).

ACCEPTED VERSION

In general, ethylene production was higher in apricots subjected to cold storage (Figure 1F) when compared to fresh fruit (Figure 1C), and also began earlier (on the 2nd day vs. 4th day, respectively). After the removal from cold storage, under room-temperature conditions, ethylene production rapidly increases in climacteric fruits, which further accelerates ripening, softening, or even some physiological disorders (tissue breakdown and browning) during shelf life (Kan *et al*., 2011; Stanley *et al*., 2013; Fan *et al*., 2018b). In fresh apricots, higher ethylene amounts were recorded in samples in which the ripening process had already commenced, especially in ripe (I_{AD} 0.01−0.40) and commercially ripe (I_{AD} 0.41−0.80) apricots. After cold storage, and at the end of shelf life, the highest ethylene peak was detected in commercially ripe apricots (I_{AD} 0.41−0.80), followed by the two groups comprising of unripe fruits (I_{AD} 0.81−1.20 and I_{AD} > 0.81) (Figure 1F).

Sensory properties of fruit

Sensory analysis (Table 1) was based on properties which make fruit more or less appealing to the consumers, as well as on the indicators associated with unfavorable or unacceptable fruit characteristics.

Insert Table 1

Fully ripe cv. "NS4" fruit (I_{AD} 0.00) after cold storage is characterized by moderate tissue breakdown and low but evident crispiness and strong sweetness, accompanied by low but identifiable sourness and intensive apricot flavor. However, fully ripe apricots may not be palatable to some consumers. After 3 days of shelf life, the tissue of fully ripe apricots is completely broken down and is devoid of any crispiness. Fruits are very sweet, almost without sourness and with very intensive apricot flavor. While the off-flavor does not increase, presence of rotting and browning reduces the commercial viability. The extent of tissue breakdown depends on several factors, including cell wall constituents, cultivar, growing and storage conditions, time of harvest, and sample size (Devaux *et al*., 2005), and manifests as sponginess, formation of a gel-like area near the stone, and a water-soaked region, which later turns brown (Devaux *et al*., 2005; Muzzaffar *et al*., 2018). As tissue breakdown affects consumer purchasing decisions, it is an important quality attribute (Arefi *et al*., 2015).

Sensory properties of ripe apricots (I_{AD} 0.01−0.40) after 21 days of cold storage did not differ significantly from those of fully ripe apricots, with the exception of a somewhat

ACCEPTED VERSION

less pronounced tissue breakdown. However, after 3 days of shelf life, the properties of ripe apricot, as well as the accompanying problems, are almost the same as in the case of fully ripe apricots.

After 21 days of cold storage, apricots cv. "NS4" harvested with I_{AD} > 0.40 exhibited insufficiently expressed sweetness and apricot aroma accompanied by low tissue breakdown and highly expressed crispiness and sourness. Intensity of emphasized sensory deficiencies, as well as the intensity of off-flavor, progressively increased with the increase in I_{AD} value at harvest, with significant differences among the ripening stage groups. After 3 days of shelf life at room temperature, sensory properties of these apricots were comparable to those noted for fully ripe apricots. Similarly, sweetness and flavor of commercially ripe apricots (I_{AD} 0.41−0.80) were comparable to fully ripe apricots, but tissue breakdown was more expressed, and crispiness was absent. Similar findings were reported by other authors (Stanley *et al.*, 2013; Fan *et al.*, 2018b). Unripe fruit (I_{AD} 0.81−1.20) was characterized by significantly lower sweetness, while completely unripe fruit (I_{AD} > 1.20) had a significantly lower intensity of apricot flavor. Defilippi *et al*. (2009) also reported lower aroma scores for less mature fruit after 30 days of storage. Even after prolonged shelf life, all fruit harvested with I_{AD} > 0.40 was characterized by more expressed sourness, which did not disappear during cold storage and shelf life. While sensory deficiencies were less pronounced in this group, according to the ANOVA results, this difference was not statistically significant. According to Nagy (2018), in cv. "Canino" apricot browning started after 20 days of cold storage at 0 °C, and gradually increased over the next 10 days.

Fruit firmness

Apricot fruit firmness during storage and shelf life is one of the major limiting factors for successful marketing, as it is among the most relevant quality attributes for consumers (Barreiro *et al*., 2004).

The flesh firmness results shown in Figure 2 indicate that it is related to the I_{AD} values at harvest. As expected, after 21 days of cold storage, flesh firmness decreased irrespective of the ripening stage, but the decline was the highest in the unripe (I_{AD} 0.81−1.20) and completely unripe (I_{AD} >1.20) groups. On the other hand, after shelf life, significantly higher flesh firmness was noted only in completely unripe (I_{AD} >1.20) apricots.

ACCEPTED VERSION

Insert Figure 2

Loss of flesh firmness in the final stages of apricot ripening is attributed to the cell wall-modifying enzymes, and includes loss of neutral sugars and liquefaction and depolymerization of cell-wall polysaccharides (Goulao and Oliveira, 2008). Changes in flesh firmness during storage depend on the storage temperature (Liu *et al*., 2017; Liu *et al.*, 2019), cultivar (Valdes *et al.*, 2009) and ripening stage (Defilippi *et al*., 2009). In the extant studies, apricot fruit retained 61−90% (Ezzat *et al.*, 2012), 41.6−45.8% (El-Badawy and El-Salhy, 2011), 16% (Valdes *et al.*, 2009), or even < 10% (Liu *et al*., 2017) of the initial flesh firmness after three weeks of storage. During shelf life, gradual degradation of pectin occurs in apricots (Fan *et al.*, 2018), resulting in the loss of its cohesion, cell wall dissolution and separation of adjacent cells. These processes may also affect cell turgor, thereby making separation of active turgor changes from passive water loss due to ongoing fruit softening a challenging task (Thomas *et al.*, 2008).

Fruit color

Fresh fully ripe apricots are characterized by bright color, ranging from yellowish-green to orange and red tones, depending on the cultivar and the ripening stage. According to the ANOVA results, both I_{AD}-based ripening stage and postharvest ripening exerted a significant influence on all measured color properties.

As shown in Table 2, the five I_{AD}-based fruit categories of cv. "NS4" were distinguished by different color tones, ranging from light orange to green, corresponding to the hue of 60.8^{o}, 63.2^{o}, 77.5^{o}, 84.6^{o} and 93^{o}, respectively. In fruit with $I_{AD} > 0.80$ at harvest, hue changed rapidly, reflecting the shift from yellowish-green to orange and red color tones, while the decrease in hue in fruit with $I_{AD} < 0.40$ was not significant.

Insert Table 2

At the beginning and throughout the experiment, ripe apricots ($I_{AD} < 0.40$) were somewhat darker in comparison to the remaining groups which had similar L* values and trends. At the beginning of the experiment, completely unripe fruit ($I_{AD} > 1.20$) was characterized by negative a* value, corresponding to a greenish skin color, but after cold storage and particularly after shelf life, red tones prevailed even in the least ripe fruit. In the fruit characterized by greater ripeness, a* increased less or even stagnated during cold

ACCEPTED VERSION

storage and shelf life. The intensity of yellow tone (b*) slightly increased in unripe fruit, while exhibiting a downward trend in more ripe fruit.

Fan *et al*. (2018) reported similar trends in L*, a* and b* in apricot fruit of low and medium maturity during cold storage at near freezing temperature or 0 °C followed by three days of shelf life. Similarly, Infante *et al*. (2008), Pérez-Pastor *et al*. (2007) and Valdes *et al*. (2009) noted a decrease in hue values in unripe apricot fruit during storage.

Fruit composition

Total soluble solids (TSS), titratable acidity (TA), as well as carotenoid, phenol and flavonoid contents, were used as indicators of differences in the apricot fruit composition in relation to the I_{AD}-based ripening stages and their changes during cold storage and shelf life (Table 3).

Insert Table 3

TSS content is an important quality attribute, and it increases as the fruit ripens, thereby influencing and contributing to the characteristic apricot taste (Muzzafar *et al*., 2018). The TSS level in apricots may range from 9.6% to 14.6%, depending on the cultivar (Caliskan *et al*., 2012). The results obtained in the present study show that TSS depends on the fruit ripening stage, as well as on the storage conditions and shelf life duration (Table 3). Among the five I_{AD}-based ripening groups, TSS at harvest gradually increased with fruit maturity. During cold storage, TSS increased regardless of the ripening stage, whereby a more prominent increase was noted in completely unripe apricots. Increase in apricot TSS after cold storage was also reported by Muftuoğlu *et al*. (2012) and Mohsen (2011). European Union (EU) regulative (R-CE No.112/2001) pertaining to marketing apricots established 10% of TSS as the minimum for consumer acceptance (Caliskan *et al.*, 2012). Even though less ripe apricots had TSS below 10% at harvest, by the end of cold storage, TSS exceeded 10% irrespective of the ripening stage.

The TA content is closely related to organic acids, and its decline may indicate metabolic changes in fruit (Maftoonazad *et al.*, 2008). As expected, at the beginning of the experiment, the highest TA was recorded in unripe apricots ($I_{AD} > 0.80$) (Table 3). During cold storage, TA remained relatively stable, but it decreased in almost all maturity groups during shelf life. After analyzing TA in five cultivars in two maturity stages, Campbell *et*

ACCEPTED VERSION

al. (2013) found difference in two cultivars, suggesting that the rate of TA change is cultivar dependent. Other authors have found that TA in apricots decreased during cold storage independently of season (El-Badawy and El-Salhy, 2011; Nagy, 2018), maturity (Defilippi *et al.*, 2009), storage duration (Lal *et al.*, 2011), and cultivar (Cui *et al.*, 2019), but also after harvest at ambient temperature (Lal *et al.*, 2011). Conversely, Defilippi *et al*. (2009) did not find a significant decrease in TA during 15 and 30 days of cold storage and shelf life, concurring with our findings for ripe apricots (I_{AD} 0.01−0.40). According to Ghasemnezhad *et al*. (2010), however, TA in apricot could initially increase during cold storage, as was the case for unripe apricots (I_{AD} 0.81−1.20), but the trend reversed after shelf life.

Apricot fruits are rich in phenolic compounds including cathecin, epicatechin, epigallocatechin, quercetin-3-glucoside, quercetin-3-rutinoside, neochlorogenic and chlorogenic acid (Campbell *et al.*, 2013). In our experiment, phenolic compound content significantly increased during cold storage in all maturity groups except completely unripe apricots (I_{AD} >1.20), as shown in Table 3. Conversely, flavonoid content decreased during cold storage as well as shelf life, with the exception of ripe (I_{AD} 0.01−0.40) and commercially ripe (I_{AD} 0.41−0.80) apricots. Increase in the total phenol content was also reported by other authors (El-Badawy and El-Salhy, 2011). Cui *et al*. (2019) demonstrated that the increase in total phenolic and total flavonoid compounds is related to the difference in cold storage temperatures. Contrary to our results, Ezzat (2019) noted a decrease in total soluble phenol content during 28 days of storage at 1 °C. Abd El-Wahab (2015) reported a decrease in total phenols during 4-week storage period in two independent production seasons. The author further noted an increase in total phenolic compounds during the transition from the commercially ripe to the tree ripe stage followed by its decrease during cold storage. More recently, Liu *et al*. (2019) reported a decrease in total phenol compounds during 4-day shelf life at 20 °C and after 20-day cold storage, while total flavonoids increased, but further cold storage resulted in their decline during shelf life.

Carotenoids are the pigments present in high quantities in apricot fruit, contributing to its flesh and skin color. Available data indicate that beta carotene is the most abundant carotenoid in apricot (Campbell *et al.*, 2013; Dragovic-Uzelac *et al.*, 2007), while other carotenoids, including zeaxanthin, beta-cryptoxanthin, γ-carotene and lutein, may be present in lower quantities, depending on the cultivar. In our experiment, carotenoid

ACCEPTED VERSION

content at harvest increased with ripeness (Table 3). It also increased in all fruits during cold storage and shelf life, with the exception of completely unripe apricots (I_{AD} > 1.20) in which carotenoid content decreased during shelf life. The increase during cold storage was more expressed in less ripe apricots. The fact that carotenoid content in apricot fruit increases during cold storage is well documented (El-Badawy and El-Salhy, 2011; Nagy, 2018), but opposing findings have also been reported, whereby Campbell *et al*. (2013) demonstrated a decrease during cold storage, along with an increase during ripening.

Sugar and organic acid composition

The changes in sugar and organic acid composition in fruit during storage may be the result of metabolic conversion of acids into sugars (gluconeogenesis), the use of organic acids through respiration (Krebs cycle), amino acid synthesis/transformations or fermentation (Echeverria and Valich, 1989; Famiani *et al*., 2015). These changes can yield valuable information regarding postharvest fruit ripening. Content and composition of sugars and organic acids is also the main determinant of sensory properties of apricots in terms of fruit sweetness and sourness.

As shown in Table 3, the apricot ripening stage exhibited significant impact only on the sucrose content. Sucrose was the most abundant sugar in apricot fruits, and its level increased as the I_{AD} value decreased. The sucrose level decreased after cold storage, but it returned to almost post-harvest value after shelf life in all but completely unripe apricots (I_{AD} > 1.20). In general, sucrose content in apricot increases as the ripening process progresses, whereas fructose and glucose contents usually increase (but may remain stable or even decrease) during fruit development (Durmaz *et al.*, 2010; Nemeth *et al.*, 2011; Bae *et al*., 2014; Xi *et al.*, 2016; Aslam *et al.*, 2019; Iqbal *et al*., 2020). Several authors have noted that, during shelf life at 5 and 10 °C, sucrose content increased. In our study, fructose content increased significantly during cold storage regardless of the ripening stage, while it remained at about the same level during shelf life. Glucose content was at about the same level at harvest, irrespective of the ripening stage, and remained stable during cold storage and shelf life. These factors were also the key determinants of the sweetness rating during the sensory assessment.

Insert Table 4

ACCEPTED VERSION

The findings reported in Table 4 related to organic acids further indicate that, in ripe apricots, malic and citric acid were dominant and were present in about equal quantities, while citric acid, strongly influenced by the ripening stage, was dominant in less ripe apricots. In fully ripe, ripe and commercially ripe apricots (I_{AD} 0.00−0.80) citric acid content did not differ significantly at harvest, but its content in unripe (I_{AD} 0.81−1.20) and particularly in completely unripe apricots (I_{AD} > 1.20) was significantly higher, contributing to more sour taste noted in the sensory assessment. In the investigations conducted by Aubert and Chanforan (2007), malic acid was dominant in 6 out of 28 apricot cultivars, while citric acid was dominant in the remaining 22. According to Ayour *et al*. (2017) in 9 out of 12 cultivars, malic acid content decreased significantly during some ripening phases. Similar results were reported for citric acid, suggesting that acid reduction rate is cultivar dependent (Ayour *et al.*, 2017). In investigations including smaller number of ripening stages, the content of organic acids usually exhibits a decreasing trend (Aubert and Chanforan, 2007; Fan *et al.*, 2017), but these findings are not substantiated by studies involving a greater number of maturity stages (Bae *at al*., 2014; Durmaz *et al.*, 2010)

In our experiment, succinic acid content was significantly affected by the ripening stage, but was also storage dependent. In particular, it tended to decrease during fruit ripening, but increased during shelf life. The highest increase in the succinic acid content during cold storage was recorded in completely unripe apricots (I_{AD} > 1.20), while the highest increase characterized fully ripe apricots (I_{AD} 0.00) during shelf life. Given that succinic acid is the product of Krebs cycle, its increase may indicate that the most intensive metabolic activity occurs in completely unripe apricots during cold storage, while in fully ripe apricots intensive metabolism is to be expected during shelf life.

Conclusions

The results yielded by the present study support the reliability of DA-meter as a useful tool for the successful classification of apricot cv. “NS4” according to its maturity, as they suggest that the physicochemical and sensory traits of this cultivar are highly affected by the I_{AD} value, cold storage and shelf life.

In particular, cv. “NS4” fruit harvested with I_{AD} < 0.40 should be designated for immediate marketing and consumption. It can also be stored for three weeks, but in this

ACCEPTED VERSION

case, it has to be consumed almost immediately after purchase. Apricots harvested as partly unripe should be marketed after prolonged storage with obligate exposure to the shelf life conditions, allowing the beneficial sensory properties to progress toward those favored in fully ripe apricot. However, some sensory properties, including higher acidity and, in extreme cases, lower sweetness and less expressed apricot aroma, accompanied by faster tissue breakdown and loss of crispiness will diminish the quality of apricots that are harvested while still unripe. At harvest, the flesh firmness of apricots analyzed as a part of this work differed due to their different I_{AD} values. Nevertheless, by the end of the study, flesh firmness decreased to a comparable level in almost all apricots, regardless of the I_{AD} values obtained at the beginning of the study. In general, after cold storage and shelf life, unripe apricots will have the L* and b* values similar to those measured for fully ripe apricot, but they will differ in the a* and hue values.

Nevertheless, further investigations with larger samples (including different cultivars) are needed for gaining a better understanding of the relationships between the mechanisms underlying each ripening phase and specific postharvest treatments. Elucidating these correlations should help in defining the most optimal maturity stage and postharvest handling method that will result in the best overall quality of fruit for the intended purpose.

ACCEPTED VERSION

Funding

This research was financed by the Ministry of Education, Science and Technological Development of Republic of Serbia [Contract number: 451-03-68/2022-14/200222] and project titled “Improvement of quality and storability of fruit by use of PGRs and growth stimulators” funded during the 2015−2019 period by Provincial Secretariat for Higher Education and Scientific Research, Autonomous Province of Vojvodina, Republic of Serbia.

Disclosure statement

The authors confirm that there are no competing interests to declare.

References

Abd El-Wahab, S. M. (2015). Apricot postharvest fruit quality, storability and marketing in response to preharvest application. Middle East J Agric Res, 4, 347-358.

Alexa, E., Lalescu, D., Berbecea, A., Camen, D., Poiana, M. A., Moigradean, D., & Bala, M. (2018). Chemical composition and antioxidant activity of some apricot varieties at different ripening stages. Chilean journal of agricultural research, 78(2), 266-275. http://dx.doi.org/10.4067/S0718-58392018000200266

Arefi, A., Moghaddam, P. A., Mollazade, K., Hassanpour, A., Valero, C., & Gowen, A. (2015). Mealiness detection in agricultural crops: destructive and nondestructive tests: a review. Comprehensive Reviews in Food Science and Food Safety, 14(5), 657-680. https://doi.org/10.1111/1541-4337.12152

Aubert, C., & Chanforan, C. (2007). Postharvest changes in physicochemical properties and volatile constituents of apricot (*Prunus armeniaca* L.). Characterization of 28 cultivars. Journal of agricultural and food chemistry, 55(8), 3074-3082. https://doi.org/10.1021/jf063476w

Ayour, J., Sagar, M., Alfeddy, M. N., Taourirte, M., & Benichou, M. (2016). Evolution of pigments and their relationship with skin color based on ripening in fruits of different Moroccan genotypes of apricots (*Prunus armeniaca* L.). Scientia Horticulturae, 207, 168-175. https://doi.org/10.1016/j.scienta.2016.05.027

Ayour, J., Sagar, M., Harrak, H., Alahyane, A., Alfeddy, M. N., Taourirte, M., & Benichou, M. (2017). Evolution of some fruit quality criteria during ripening of twelve new Moroccan apricot clones (*Prunus armeniaca* L.). Scientia Horticulturae, 215, 72-79. https://doi.org/10.1016/j.scienta.2016.12.010

Bae, H., Yun, S. K., Yoon, I. K., Nam, E. Y., Kwon, J. H., & Jun, J. H. (2014). Assessment of organic acid and sugar composition in apricot, plumcot, plum, and peach during fruit development. Journal of Applied Botany and Food Quality, 87. DOI:10.5073/JABFQ.2014.087.004

Barreiro, P., Ruiz-Altisent, M., Valero, C., & García-Ramos, J. (2004). Fruit postharvest technology: instrumental measurement of ripeness and quality. In Production practices and quality assessment of food crops (pp. 321-340). Springer, Dordrecht. DOI: 10.1007/1-4020-2534-3_12

Bartolini, S., Viti, R., & Zanol, G. C. (2005, June). Apricot cultivars and cold storage affect the total antioxidant capacity and glutathione content in fruit. In XIII International Symposium on Apricot Breeding and Culture 717 (pp. 359-362). https://doi.org/10.17660/ActaHortic.2006.717.72

ACCEPTED VERSION

Brummell, D. A., Dal Cin, V., Crisosto, C. H., & Labavitch, J. M. (2004). Cell wall metabolism during maturation, ripening and senescence of peach fruit. Journal of experimental botany, 55(405), 2029-2039. https://doi.org/10.1093/jxb/erh227

Bureau, S., Renard, C. M., Reich, M., Ginies, C., & Audergon, J. M. (2009). Change in anthocyanin concentrations in red apricot fruits during ripening. LWT-Food Science and Technology, 42(1), 372-377. https://doi.org/10.1016/j.lwt.2008.03.010

Caliskan, O., Bayazit, S., & Sumbul, A. (2012). Fruit quality and phytochemical attributes of some apricot (*Prunus armeniaca* L.) cultivars as affected by genotypes and seasons. Notulae Botanicae Horti Agrobotanici Cluj-Napoca, 40(2), 284-294. DOI: https://doi.org/10.15835/nbha4028044

Campbell, O. E., Merwin, I. A., & Padilla-Zakour, O. I. (2013). Characterization and the effect of maturity at harvest on the phenolic and carotenoid content of Northeast USA apricot (Prunus armeniaca) varieties. Journal of Agricultural and Food Chemistry, 61(51), 12700-12710. https://doi.org/10.1021/jf403644r

Costa, G., Fiori, G., Rocchi, L., Vidoni, S., Berthod, N., Besse, S., ... & Rossier, J. (2018). Prototype of a stationary DA device to group apricot fruits in classes of homogeneous ripening. Acta horticulturae 1214, 111-116. https://doi.org/10.17660/ActaHortic.2018.1214.19

Costa, G., Noferini, M., Fiori, G., & Torrigiani, P. (2009). Use of Vis/NIR spectroscopy to assess fruit ripening stage and improve management in post-harvest chain. Fresh Prod, 1, 35-41.

Costa, G., Vidoni, S., & Rocchi, L. (2014, August). Use of non-destructive devices to support pre-and postharvest fruit management. In XXIX International Horticultural Congress on Horticulture: Sustaining Lives, Livelihoods and Landscapes (IHC2014): 1119 (pp. 329-335). https://doi.org/10.17660/ActaHortic.2016.1119.45

Costache, M. A., Campeanu, G. H. E. O. R. G. H. E., & Neata, G. (2012). Studies concerning the extraction of chlorophyll and total carotenoids from vegetables. Romanian Biotechnological Letters, 17(5), 7702-7708.

Cui, K., Zhao, H., Sun, L., Yang, L., Cao, J., & Jiang, W. (2019). Impact of near freezing temperature storage on postharvest quality and antioxidant capacity of two apricot (*Prunus armeniaca* L.) cultivars. Journal of food biochemistry, 43(7), e12857. https://doi.org/10.1111/jfbc.12857

ACCEPTED VERSION

D'Ambrosio, C., Arena, S., Rocco, M., Verrillo, F., Novi, G., Viscosi, V., ... & Scaloni, A. (2013). Proteomic analysis of apricot fruit during ripening. Journal of proteomics, 78, 39-57. https://doi.org/10.1016/j.jprot.2012.11.008

Defilippi, B. G., San Juan, W., Valdes, H., Moya-Leon, M. A., Infante, R., & Campos-Vargas, R. (2009). The aroma development during storage of Castlebrite apricots as evaluated by gas chromatography, electronic nose, and sensory analysis. Postharvest Biology and Technology, 51(2), 212-219. https://doi.org/10.1016/j.postharvbio.2008.08.008

Devaux, M. F., Barakat, A., Robert, P., Bouchet, B., Guillon, F., Navez, B., & Lahaye, M. (2005). Mechanical breakdown and cell wall structure of mealy tomato pericarp tissue. Postharvest Biology and Technology, 37(3), 209-221. https://doi.org/10.1016/j.postharvbio.2005.04.013

Doerflinger, F. C., Nock, J. F., Al Shoffe, Y., Shao, X., & Watkins, C. B. (2014, August). Non-destructive maturity assessment of' 'Empire' apples treated with preharvest inhibitors of ethylene perception and production with a delta absorbance (DA) meter. In XXIX International Horticultural Congress on Horticulture: Sustaining Lives, Livelihoods and Landscapes (IHC2014): 1119 (pp. 227-234). https://doi.org/10.17660/ActaHortic.2016.1119.32

Dragovic-Uzelac, V., Levaj, B., Mrkic, V., Bursac, D., & Boras, M. (2007). The content of polyphenols and carotenoids in three apricot cultivars depending on stage of maturity and geographical region. Food chemistry, 102(3), 966-975. https://doi.org/10.1016/j.foodchem.2006.04.001

Durmaz, G., Cam, M., Kutlu, T., & HIşIL, Y. (2010). Some physical and chemical changes during fruit development of five common apricot (*Prunus armeniaca* L.) cultivars. Food Science and Technology Research, 16(1), 71-78. https://doi.org/10.3136/fstr.16.71

Echeverria, E., & Valich, J. (1989). Enzymes of sugar and acid metabolism in stored'Valencia'oranges. Journal of the American Society for Horticultural Science (USA).

El-Badawy, H. E. M., & El-Salhy, F. T. A. (2011). Physical and chemical properties of Canino apricot fruits during cold storage as influenced by some post-harvest treatments. Australian Journal of Basic and Applied Sciences, 5(9), 537-548.

Ezzat, A. (2019). Apricot fruit chilling injuries during the cold storage affected by harvest maturity. International Journal of Horticultural Science, 25(3-4), 28-31.

ACCEPTED VERSION

Ezzat, A., Nyéki, J., Soltész, M., Amriskó, L., Balázs, G. I., Mikita, T., & Szabó, Z. (2012). Storability of some apricot varieties as affected by storage period. International Journal of Horticultural Science, 18(1), 39-42.

Famiani, F., Battistelli, A., Moscatello, S., Cruz-Castillo, J. G., & Walker, R. P. (2015). The organic acids that are accumulated in the flesh of fruits: occurrence, metabolism and factors affecting their contents-a review. Revista Chapingo. Serie horticultura, 21(2), 97-128. https://doi.org/10.5154/r.rchsh.2015.01.004

Fan, X., Argenta, L., & Mattheis, J. P. (2000). Inhibition of ethylene action by 1-methylcyclopropene prolongs storage life of apricots. Postharvest Biology and Technology, 20(2), 135-142. https://doi.org/10.1016/S0925-5214(00)00121-6

Fan, X., Shu, C., Zhao, K., Wang, X., Cao, J., & Jiang, W. (2018b). Regulation of apricot ripening and softening process during shelf life by post-storage treatments of exogenous ethylene and 1-methylcyclopropene. Scientia Horticulturae, 232, 63-70. https://doi.org/10.1016/j.scienta.2017.12.061

Fan, X., Xi, Y., Zhao, H., Liu, B., Cao, J., & Jiang, W. (2018a). Improving fresh apricot (*Prunus armeniaca* L.) quality and antioxidant capacity by storage at near freezing temperature. Scientia Horticulturae, 231, 1-10. https://doi.org/10.1016/j.scienta.2017.12.015

Fan, X., Zhao, H., Wang, X., Cao, J., & Jiang, W. (2017). Sugar and organic acid composition of apricot and their contribution to sensory quality and consumer satisfaction. Scientia Horticulturae, 225, 553-560. https://doi.org/10.1016/j.scienta.2017.07.016

Ghasemnezhad, M., Shiri, M. A., & Sanavi, M. (2010). Effect of chitosan coatings on some quality indices of apricot (Prunus armeniaca L.) during cold storage. Caspian journal of environmental sciences, 8(1), 25-33.

Goulao, L. F., & Oliveira, C. M. (2008). Cell wall modifications during fruit ripening: when a fruit is not the fruit. Trends in Food Science & Technology, 19(1), 4-25. https://doi.org/10.1016/j.tifs.2007.07.002

Hegedüs, A., Pfeiffer, P., Papp, N., Abrankó, L., Blázovics, A., Pedryc, A., & Stefanovits-Bányai, É. (2011). Accumulation of antioxidants in apricot fruit through ripening: characterization of a genotype with enhanced functional properties. Biological Research, 44(4), 339-344. http://dx.doi.org/10.4067/S0716-97602011000400004

Infante, R., Meneses, C., & Defilippi, B. G. (2008). Effect of harvest maturity stage on the sensory quality of 'Palsteyn'apricot (*Prunus armeniaca* L.) after cold storage. The

ACCEPTED VERSION

Journal of Horticultural Science and Biotechnology, 83(6), 828-832. https://doi.org/10.1080/14620316.2008.11512468

Kan, J., Che, J., Xie, H. Y., & Jin, C. H. (2011). Effect of 1-methylcyclopropene on postharvest physiological changes of 'Zaohong'plum. Acta physiologiae plantarum, 33(5), 1669-1677. https://doi.org/10.1007/s11738-010-0703-7

Lal, S., Kumar, D., Singh, D. B., Ahmed, N., Kumar, R., & Dar, G. A. (2011). Effect of pre-harvest application of calcium chloride and gibberellic acid on shelf-life and post-harvest quality of apricot (Prunus armeniaca L.) cv. Harcot. Journal of Horticultural Sciences, 6(1), 46-51.

Larrauri, J. A., Rupérez, P., & Saura-Calixto, F. (1997). Mango peel fibres with antioxidant activity. Zeitschrift für Lebensmitteluntersuchung und-Forschung A, 205(1), 39-42. https://doi.org/10.1007/s002170050120

Leccese, A., Bartolini, S., & Viti, R. (2007). Total antioxidant capacity and phenolics content in apricot fruits. International Journal of Fruit Science, 7(2), 3-16. https://doi.org/10.1300/J492v07n02_02

Liu, B., Zhao, H., Fan, X., Jiao, W., Cao, J., & Jiang, W. (2019). Near freezing point temperature storage inhibits chilling injury and enhances the shelf life quality of apricots following long-time cold storage. Journal of Food Processing and Preservation, 43(7), e13958. https://doi.org/10.1111/jfpp.13958

Liu, H., Chen, F., Lai, S., Tao, J., Yang, H., & Jiao, Z. (2017). Effects of calcium treatment and low temperature storage on cell wall polysaccharide nanostructures and quality of postharvest apricot (Prunus armeniaca). Food Chemistry, 225, 87-97. https://doi.org/10.1016/j.foodchem.2017.01.008

Maftoonazad, N., Ramaswamy, H. S., & Marcotte, M. (2008). Shelf-life extension of peaches through sodium alginate and methyl cellulose edible coatings. International journal of food science & technology, 43(6), 951-957. https://doi.org/10.1111/j.1365-2621.2006.01444.x

Mandić A, Kevrešan Ž, Mastilović J, 2019. Development and validation of static headspace gas chromatography with flame ionization detection method for determination of ethylene. Proc. 6th SEE International Postharvest Conference; „Quality Management in Postharvest Systems", 26-28 June, Novi Sad, Serbia, 65.

Melgarejo, P., Calín-Sánchez, Á., Carbonell-Barrachina, Á. A., Martínez-Nicolás, J. J., Legua, P., Martínez, R., & Hernández, F. (2014). Antioxidant activity, volatile composition and sensory profile of four new very-early apricots (*Prunus armeniaca*

ACCEPTED VERSION

L.). Journal of the Science of Food and Agriculture, 94(1), 85-94. https://doi.org/10.1002/jsfa.6201

Mohsen, A. T. (2011). Performance of peach and apricot fruit at cold storage and shelf life as affected by modified atmosphere packaging. American-Eurasian J. Agric. &Environ. Sci, 10(5), 718-727.

Muftuoğlu, F., Ayhan, Z., & Esturk, O. (2012). Modified atmosphere packaging of Kabaaşı apricot (Prunus armeniaca L.'Kabaaşı'): effect of atmosphere, packaging material type and coating on the physicochemical properties and sensory quality. Food and Bioprocess Technology, 5(5), 1601-1611. https://doi.org/10.1007/s11947-010-0482-6

Muzzaffar, S., Bhat, M. M., Wani, T. A., Wani, I. A., & Masoodi, F. A. (2018). Postharvest biology and technology of apricot. In Postharvest biology and technology of temperate fruits (pp. 201-222). Springer, Cham. DOI: 10.1007/978-3-319-76843-4_8

Nagy, N. (2018). Effect of Preharvest Applications Oof Calcium, Anti-Ethylene Compounds and their Combinations on "Canino" Apricot Fruit Quality and Storability. Zagazig Journal of Agricultural Research, 45(5), 1609-1631. https://dx.doi.org/10.21608/zjar.2018.48421

Németh, S., Szalay, L., Ficzek, G., Stéger-Máté, M., Sándor, G., Végvári, G., & Tóth, M. (2011). Analysis of chemical parameters determining the fruit quality of apricot cultivars during ripening. Acta alimentaria, 40(Supplement-1), 109-119. https://doi.org/10.1556/aalim.40.2011.suppl.11

Pękal, A., & Pyrzynska, K. (2014). Evaluation of aluminium complexation reaction for flavonoid content assay. Food Analytical Methods, 7(9), 1776-1782. https://doi.org/10.1007/s12161-014-9814-x

Pérez-Pastor, A., Ruiz-Sánchez, M. C., Martínez, J. A., Nortes, P. A., Artés, F., & Domingo, R. (2007). Effect of deficit irrigation on apricot fruit quality at harvest and during storage. Journal of the Science of Food and Agriculture, 87(13), 2409-2415. https://doi.org/10.1002/jsfa.2905

Sadar, N., & Zanella, A. (2019). A Study on the Potential of IAD as a Surrogate Index of Quality and Storability in cv.'Gala'Apple Fruit. Agronomy, 9(10), 642. https://doi.org/10.3390/agronomy9100642

Singleton, V. L., Orthofer, R., & Lamuela-Raventós, R. M. (1999). [14] Analysis of total phenols and other oxidation substrates and antioxidants by means of folin-ciocalteu

ACCEPTED VERSION

reagent. In Methods in enzymology (Vol. 299, pp. 152-178). Academic press. https://doi.org/10.1016/S0076-6879(99)99017-1

Spadoni, A., Cameldi, I., Noferini, M., Bonora, E., Costa, G., & Mari, M. (2016). An innovative use of DA-meter for peach fruit postharvest management. Scientia Horticulturae, 201, 140-144. https://doi.org/10.1016/j.scienta.2016.01.041

Stanley, J., Prakash, R., Marshall, R., & Schröder, R. (2013). Effect of harvest maturity and cold storage on correlations between fruit properties during ripening of apricot (Prunus armeniaca). Postharvest biology and technology, 82, 39-50. https://doi.org/10.1016/j.postharvbio.2013.02.020

Thomas, T. R., Shackel, K. A., & Matthews, M. A. (2008). Mesocarp cell turgor in Vitis vinifera L. berries throughout development and its relation to firmness, growth, and the onset of ripening. Planta, 228(6), 1067-1076. https://doi.org/10.1007/s00425-008-0808-z

Valdes, H. H., Pizarro, M. M., Campos-Vargas, R. R., Infante, R. R., & Defilippi, B. (2009). Effect of ethylene inhibitors on quality attributes of apricot cv. Modesto and Patterson during storage. Chilean journal of agricultural research, 69(2), 134-144.

Vanoli, M., & Buccheri, M. (2012). Overview of the methods for assessing harvest maturity. https://doi.org/10.2212/spr.2012.1.4

Vardi, N., Parlakpinar, H., Ozturk, F., Ates, B., Gul, M., Cetin, A., ... & Otlu, A. (2008). Potent protective effect of apricot and β-carotene on methotrexate-induced intestinal oxidative damage in rats. Food and chemical toxicology, 46(9), 3015-3022. https://doi.org/10.1016/j.fct.2008.05.039

Zhang, P., Wei, Y., Xu, F., Wang, H., Chen, M., & Shao, X. (2020). Changes in the chlorophyll absorbance index (I AD) are related to peach fruit maturity. New Zealand Journal of Crop and Horticultural Science, 48(1), 34-46. https://doi.org/10.1080/01140671.2019.1664598

Ziosi, V., Noferini, M., Fiori, G., Tadiello, A., Trainotti, L., Casadoro, G., & Costa, G. (2008). A new index based on vis spectroscopy to characterize the progression of ripening in peach fruit. Postharvest biology and technology, 49(3), 319-329. https://doi.org/10.1016/j.postharvbio.2008.01.017

ACCEPTED VERSION

Figure 1. Weight loss, respiration rate, and ethylene production of apricots classified into five ripening stages after the harvest followed by six days of shelf life (A, B, C) and cold storage followed by four days of shelf life (D, E, F). Columns denoted with different letters are statistically significantly different ($p < 0.05$).

Figure 2. Fruit firmness of apricot fruit classified into five ripening stages after the harvest and 21 days of cold storage followed by shelf life * statistically significant values are denoted with different letters ($p < 0.05$)

ACCEPTED VERSION

Table 1. Sensory evaluation of apricot fruit classified into five ripening stages after the harvest, cold storage and shelf life.

Ripening stage	I_{AD} value	Tissue breakdown	Sweetness	sourness	Crispiness	Apricot flavor	Pit burning	Rotting	Off flavor
After cold storage									
I	0.00	32.5^{c}	61.5^{e}	12.8^{abc}	14.0^{b}	61.5^{cd}	0	0	3.8
II	0.01−0.40	25^{d}	59.2^{e}	19.2^{abcd}	17.0^{b}	60.5^{cd}	2.5	0	0.0
III	0.41−0.80	12.5^{e}	41.2^{d}	29.8^{de}	30.5^{c}	47.0^{c}	2.5	0	0.7
IV	0.81−1.20	5^{f}	25.3^{b}	48.7^{fg}	51.8^{d}	22.5^{a}	2.5	0	1.8
V	>1.20	0^{g}	9.8^{a}	62.2^{g}	65.3^{e}	10.8^{a}	0	0	11.7
After shelf life									
I	0.00	100^{a}	68.1^{e}	6.0^{a}	0.0^{a}	73.0^{d}	7	30^{a}	2.9
II	0.01−0.40	85^{ab}	56.9^{e}	8.4^{ab}	0.3^{a}	70.1^{d}	6	15^{b}	2.9
III	0.41−0.80	72.5^{b}	56.9^{e}	22.9^{bcde}	0.3^{a}	66.6^{d}	5	5^{c}	0.0
IV	0.81−1.20	70^{b}	45.7^{cd}	27.9^{cde}	11.1^{b}	56.9^{cd}	1	0	1.9
V	>1.20	25^{d}	35.1^{d}	38.9^{ef}	26.9^{c}	38.1^{b}	5	5^{c}	3.3
Significance of effects									
Storage		**	**	**	**	**	NS	*	NS
Ripening stage		**	**	**	**	**	NS	NS	NS

* statistically significant values are denoted with different letters ($p < 0.05$); ** significantly affected by the treatment ($p < 0.05$); NS – not significant

ACCEPTED VERSION

Table 2. The color of apricots classified into five ripening stages at harvest, after cold storage and shelf life.

Ripening stage, I_{AD} value		**Storage, days**	**L***	**a***	**b***	**h**
	0.00	0	58.0^{bc}	20.0^{gh}	36.8^{bc}	60.8^{ab}
I	0.00	21	55.6^{b}	21.2^{h}	37.1^{bc}	60.0^{ab}
	0.00	21+3	50.3^{a}	17.6^{fg}	27.6^{a}	57.1^{a}
	0.01−0.40	0	59.3^{cd}	18.7^{gh}	37.8^{bc}	63.2^{bc}
II	0.01−0.40	21	55.6^{b}	21.2^{h}	36.8^{bc}	59.7^{ab}
	0.01−0.40	21+3	52.3^{a}	18.4^{gh}	30.5^{a}	58.6^{ab}
	0.41−0.80	0	62.2^{e}	9.0^{cd}	40.2^{cd}	77.5^{e}
III	0.41−0.80	21	59.2^{cd}	14.4^{e}	41.3^{d}	70.8^{d}
	0.41−0.80	21+3	57.0^{bc}	14.9^{ef}	37.5^{bc}	68.2^{cd}
	0.81−1.20	0	61.4^{de}	3.4^{b}	38.6^{cd}	84.6^{g}
IV	0.81−1.20	21	59.1^{cd}	9.4^{cd}	40.2^{cd}	76.6^{e}
	0.81−1.20	21+3	57.2^{bc}	11.2^{d}	37.8^{bc}	73.1^{de}
	>1.20	0	58.8^{cd}	-2.1^{a}	34.8^{b}	93.0^{h}
V	>1.20	21	58.4^{c}	4.0^{b}	37.2^{bc}	83.5^{fg}
	>1.20	21+3	57.9^{bc}	7.3^{c}	37.0^{bc}	78.6^{ef}
Storage			**	**	**	**
Ripening stage			**	**	**	**

L* − lightness; a* − intensity of red tone; b* − intensity of yellow tone; h – hue; * statistically significant values are denoted with different letters ($p < 0.05$); ** significantly affected by the treatment ($p < 0.05$)

ACCEPTED VERSION

Table 3. TSS%, TA (malic acid/100 g), phenols (mg/100 g), flavonoids (mg quercetin/100 g) and carotenoids (mg/100 g FW) in apricots classified into five ripening stages at harvest and after cold storage followed by shelf life.

Ripening stage, I_{AD} value		Storage, days	TSS	TA	Phenols	Flavonoids	Carotenoids
	0.00	0	10.6^{g}	2.34^{bc}	46.1^{bc}	8.47^{k}	2.43^{g}
I	0.00	21	11.4^{k}	2.35^{bc}	54.7^{g}	5.52^{d}	2.93^{hi}
	0.00	21+3	11.8^{n}	2.24^{a}	58.3^{hi}	5.83^{e}	3.79^{l}
	0.01−0.40	0	10.0^{d}	2.41^{bcd}	38.5^{a}	6.16^{f}	1.60^{d}
II	0.01−0.40	21	11.0^{j}	2.40^{bcd}	59.2^{i}	6.84^{g}	2.99^{i}
	0.01−0.40	21+3	11.6^{m}	2.37^{bcd}	52.8^{f}	5.03^{c}	3.44^{k}
	0.41−0.80	0	9.8^{c}	2.41^{bcd}	44.7^{b}	7.61^{i}	1.47^{c}
III	0.41−0.80	21	10.6^{g}	2.32^{ab}	54.7^{g}	8.07^{j}	2.86^{h}
	0.41−0.80	21+3	11.5^{l}	2.54^{f}	49.1^{de}	5.62^{d}	3.21^{j}
	0.81−1.20	0	9.6^{b}	2.45^{de}	48.6^{d}	8.66^{l}	1.36^{b}
IV	0.81−1.20	21	10.4^{f}	2.52^{ef}	57.6^{h}	7.32^{h}	2.17^{f}
	0.81−1.20	21+3	10.8^{i}	2.35^{bc}	46.8^{c}	5.61^{d}	2.52^{g}
	>1.20	0	8.6^{a}	2.58^{f}	48.6^{d}	7.21^{h}	0.76^{a}
V	>1.20	21	10.2^{e}	2.57^{f}	49.3^{de}	4.43^{b}	1.86^{e}
	>1.20	21+3	10.7^{h}	2.42^{cd}	50.3^{e}	4.16^{a}	1.45^{bc}
		Ripening stage	**	**	**	**	**
		Storage	**	**	**	**	**

* statistically significant values are denoted with different letters ($p < 0.05$); ** significanly affected by the treatment ($p < 0.05$)

ACCEPTED VERSION

Table 4. Content of sugars (fructose, glucose and sucrose, g/100 g FW) and organic acids (malic, citric and succinic, mg/100 g FW) in apricot fruit classified into five ripening stages at harvest and after cold storage followed by shelf life.

Ripening stage, I_{AD} value		**Storage, days**	**Fructose**	**Glucose**	**Sucrose**	**Malic acid**	**Citric acid**	**Succinic acid**
	0.00	0	1.18^{ab}	0.88	6.33^{ef}	1.68	1.61^{a}	0.526^{ab}
I	0.00	21	1.44^{cd}	0.91	6.03^{def}	1.58	1.57^{a}	0.498^{a}
	0.00	21+3	1.38^{bc}	0.86	6.47^{f}	1.60	1.56^{a}	0.729^{c}
	0.01−0.40	0	1.17^{ab}	0.88	5.56^{de}	1.66	1.61^{a}	0.677^{c}
II	0.01−0.40	21	1.50^{cd}	0.87	4.52^{c}	1.52	1.67^{a}	0.654^{bc}
	0.01−0.40	21+3	1.43^{cd}	0.86	5.46^{d}	1.56	1.59^{a}	0.783^{c}
	0.41−0.80	0	1.10^{a}	0.85	5.57^{de}	1.68	1.98^{ab}	0.634^{abc}
III	0.41−0.80	21	1.50^{cd}	0.89	4.64^{c}	1.58	1.95^{ab}	0.649^{d}
	0.41−0.80	21+3	1.52^{cd}	0.90	4.36^{bc}	1.64	2.14^{bc}	0.966^{d}
	0.81−1.20	0	1.12^{a}	0.89	4.53^{c}	1.58	2.50^{cd}	0.784^{c}
IV	0.81−1.20	21	1.48^{cd}	0.89	3.72^{b}	1.66	2.73^{d}	0.751^{c}
	0.81−1.20	21+3	1.52^{cd}	0.89	4.43^{bc}	1.71	2.70^{d}	1.003^{d}
	>1.20	0	1.04^{a}	0.85	3.69^{b}	1.56	3.20^{e}	0.787^{c}
V	>1.20	21	1.68^{cd}	0.88	2.42^{a}	1.59	3.13^{e}	1.302^{e}
	>1.20	21+3	1.63^{cd}	0.90	2.52^{a}	1.59	3.21^{e}	0.942^{d}
	Ripening stage		NS	NS	**	NS	**	**
	Storage		**	NS	**	NS	NS	**

* statistically significant values are denoted with different letters ($p < 0.05$); ** significantly affected by the treatment ($p < 0.05$); NS – not significant

ACCEPTED VERSION