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ORIGINAL RESEARCH PAPER

THE USE OF MODIFIED ATMOSPHERE PACKAGING AS MEAN OF BIOACTIVE COMPOUNDS AND ANTIOXIDANT ACTIVITIES PRESERVATION OF FRESH FIGS (*FICUS CARICA* L.) FROM RARE CULTIVARS

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Abstract

Fresh figs belong to a group of foods that perish rapidly. If they are not preserved correctly, their nutritional and high bioactive compounds could be easily lost in few days. The aim of this work is to extend shelf life of two rare Algerian fresh fig cultivars: *Abakour-aberkane* and *Tahayounte*. Experiments were carried out by studying the conservation effect under modified atmosphere packaging (MAP), either with the presence or absence of ethylene absorbent ($KMnO_4$). Physicochemical parameters, bioactive compound contents (phenolic, flavonoid, anthocyanin, carotenoid, and ascorbic acid contents), and antioxidant activities (free radical scavenging activity and ferrous ions chelating activity) were monitored at 5 and 10 days of storage at 4°C. The use of MAP had allowed the extension of figs shelf life during storage; with retarding the ripening process by recording a slight decrease in bioactive compounds and expressed a moderate antioxidant activities. In this regard, the application of the latter conservation modality can enhance the studied fresh figs sale for a moderate period.

Keywords: fig (*Ficus carica* L.), effect of storage, modified atmosphere packaging, bioactive compounds, antioxidant activity

Introduction

The fig (*Ficus carica* L.) is belonging to the Moraceae family. It is principally originated from southwest Asia. However, figs as fruits are widely distributed in the Mediterranean area and belonging to the alimentation diet of this region (Caliskan and Polat, 2011). Figs are an important source of nutritional values that

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contribute to a healthy diet, because of their composition of vitamins, minerals, sugars, fibers, and free fat fruits (Crisosto *et al.,* 2010). Additionally, figs contain compounds with antioxidant proprieties such as vitamin C, phenolic acids, flavonoids, and carotenoids (Palmeira *et al.,* 2019). Bioactive compounds contribute essentially to fruits quality (fruit appearance, taste, and flavor) and occurre in various health-promoting potential (antioxidant, anti-inflammatory, antibacterial, and antiviral activities) (Arvaniti *et al.,* 2019). Figs are consumed either fresh or dried and most of the annual production of figs is destined to the storage, generally by drying them, because of the highly perishable nature and limited shelf life of fresh figs (Bahar and Lichter, 2018). However, several rare fig cultivars are threatened by the largely cultivated ones, which are easily dried allowing a long storage period and then the reduction of postharvest losses of fruits. This cultivars selection is affecting the agro-biodiversity of the fig tree in Algeria and the all the benefits of consuming fresh figs from different cultivars and varieties.

Figs are climacteric fruits with moderate ethylene respiration. It is well known that the production of ethylene during storage induces the acceleration of ripening and senescence and then the loss of firmness, spoilage, softening and reduction of the nutritional value of fruits (Allegra *et al.,* 2017). Besides a high water activity, fresh figs had very thin skin easily damaged leading to a deterioration of fruit. As consequences, the shelf life of figs is limited and the commercialization aptitude of fresh figs is reduced (Irfan *et al.,* 2013). One of the significant factors for maintaining fruit quality and avoiding spoilage of fresh figs is the use of low temperature during storage, especially when the fruit is considered to be not sensitive to chilling injury (Irfan *et al.,* 2013). Therefore, it is necessary to apply post-harvest methods of conservation to extend shelf life of figs. In the literature, one of the most techniques used for controlling the highly perishable nature of fresh figs is the storage under modified atmosphere packaging (MAP) at low temperatures. This technique consists of controlling the internal atmosphere of the packaging and taking into account the type of fruit ripening (climacteric or non-climacteric fruits) and the gas permeability of the packaging (Martínez-Romero *et al.,* 2003). This process leads to accumulate a high amount of carbon dioxide (CO_2) and a low oxygen (O_2) level inside the package. MAP is associated with low temperature (cold storage) in order to limit the undesirable effect of gases (Martínez-Romero *et al.,* 2003). The beneficial effects of MAP are reducing metabolism activity, reducing chilling injury, and as well as delaying changes in properties related to the ripening process and extending the shelf life of fruits (Villalobos *et al.,* 2014). Some examples of the wide use of MAP on figs are reported by Villalobos *et al.* (2015a) on Albacor packed on high of CO_2 and low of O_2 concentrations, delay the postharvest disorders caused by fungal proliferation and extend the time of cold storage. Also, as reported by Villalobos *et al.* (2014), the application of MAP on several fig varieties (*Cuello Dama Blanco*, *Cuello Dama Negro*, *San Antonio*, and breba) had a good effect on the fruits extension shelf life, and these authors claimed the importance of the cultivars on the determination of fruits extension times.

Based on the state of art of MAP techniques, the purpose of this study was to extend the shelf life of figs from two Algerian rare cultivars *Abakour-aberkane* (AB) and *Tahayounte* (HA) which are appreciated by the consumer but are not largely cultivated because of their short shelf life and they are not suitable for drying. In order to inhibit the action of ethylene, we combined MAP with a potassium permanganate $KMnO_4$, known as an oxidizer or absorbent of ethylene.

In this regard, we evaluated the effect of storage under modified atmosphere packaging with or without potassium permanganate on physicochemical parameters, bioactive compounds, and antioxidant activities of the studied fruits conserved at 4°C.

In a long term, this work aims also to contribute for the preservation of the agro-biodiversity of fig trees in Algeria by maintaining the freshness of threatened fig cultivars in order to facilitate their sale, and on the other hand, to promote the consumption of fresh fruits known as an important source of micronutrients and bioactive compounds.

Materials and methods

Standards and reagents

Folin–Ciocalteu reagent, acetone, ethanol (purity 96%) and ascorbic acid were from VWR Prolabo (Fontenay-Sous-Bois, France); hexane, HCl, gallic acid, aluminium chloride, methanol, sodium carbonate anhydrous and potassium permanganate were from Biochem, Chemopharma (Quebec, Canada); quercetin (purity 97%) was from Alfa Aesar (Karlsruhe, Germany); DPPH (2-2-diphenyl-1-picrylhydrazyl), and ß-carotene were from Sigma-Aldrich GmbH (Darmstadt, Germany); Ferrozin (3-(2-Pyridyl)-5,6-diphenyl-1,2,4-triazine-4',4''-disulfonic acid sodium salt hydrate) (purity≥97%) and DCIP (2,6-dichlorophenolindophenol) were from Sigma-Aldrich (St. Louis, USA).

Plant material

Fig fruits (*Ficus carica* L.) were harvested in August 21, 2017, in an orchard located in Beni Maouche (36°28'41" N 4°38'17" E), Bejaia, North of Algeria. Two fig cultivars were studied; *Abakour-aberkane*, a biferous cultivar with fruits characterized by black skin color and *Tahayounte* cultivar with yellow-green skin fruits (Figure 3). Figs were picked at the commercial ripening stage according to their firmness and skin color and immediately transported to the laboratory under cold conditions. Once there, fruits with physical damage were discarded and the chosen fruits were randomly assigned to each treatment.

Packaging of fruits

About 300 g of similar fruits were selected for each treatment that represented by eight fruits of AB cultivar and six of HA. Fruits were packed in polyethylene (PET) punnets (22 cm (L) x 14 cm (w) x 4 cm (h); 1232 cm^3). Punnets were perforated in order to provide modified atmosphere packaging (MAP). In batch P, three punnets of AB and HA cultivars of each experiment of day storage (5 and 10) were perforated per 50 mm (Ø 100 µm, a total of 16 holes), for P1 (5 days) and for P2 (10 days). In batch PE, AB and HA fruits were packed in punnets with pieces of

chalks ($KMnO_4$: ethylene absorbent) during each experiment day (5 and 10), the punnets were perforated per 50 mm (Ø 100 µm, a total of 16 holes). Ethylene absorbent was prepared by dipping pieces of chalks in solutions of potassium permanganate ($KMnO_4$) at a concentration of 2500 ppm and dried at 100°C for 1 hour. Fruits without any post-harvest proceedings were considered as control batch. All batches were prepared in triplicate and stored at 4°C.

Physicochemical parameters

In order to prepare the samples for physicochemical and other analysis, figs of each treatment were ground (A11 basic grinder, IKA, Germany). The total soluble solids (TSS) were determined by a refractometer (ABBE type refractometer AR 12, SCHMIDT and HAENSCH, Germany) and the result was expressed as degree of Brix (°Bx). After homogenization of 5 g of figs in 50 mL of distilled water, the pH was determined by pH-meter (Bante 920 Benchtop pH/ORP Meter, China).

Determination of bioactive compounds

Extraction of samples

Phenolic compounds of figs were extracted according to the optimized procedures described by Bachir Bey *et al*. (2013). Two hundred milligrams of sample were added to 10 mL of aqueous acetone (60 %, v/v), and the mixture was let under agitation by using a bath shaker (WB22, Memmert, Osterode, Germany) at 40°C for 2 h, and the extract was recovered by centrifugation at 1700 x g for 10 min.

Total phenolic content

Total phenolic contents (TPC) were measured according to Singleton and Rossi (1965). Two hundred microliters of the extract were mixed with 1000 µL of Folin-Ciocalteu reagent (diluted 10-fold with distilled water) and 800 µL of sodium carbonate (7.5%). After 30 min of incubation in darkness, the absorbance was read at 760 nm by UV-Vis spectrophotometer (Uvline 9400, Secomam, France). The results were calculated using a calibration curve prepared using gallic acid as standard ($Y=11.354x$; $R^2=0.997$), and the TPC was expressed as milligrams gallic acid equivalent per 100 grams of fresh weight (mg GAE/100 g FW).

Total flavonoid content

Total flavonoid contents (TFC) were assessed based on the method described by Djeridane *et al*. (2006). One milliliter of aluminum chloride solution ($AlCl_3$, 2 %, dissolved in methanol) was added to 1 mL of extract. The absorbance was read at 430 nm after 10 min and results were calculated using a calibration curve and quercetin as standard ($y=48.872x$; $R^2=0.997$). TFC were expressed as milligrams quercetin equivalent per 100 grams of fresh weight (mg QE/100 g FW).

Anthocyanin content

Anthocyanin contents were determined as described by Bachir Bey and Louaileche (2015). An aliquot of 900 µL of the extract was added to 900 µL of methanol-HCl (0.1 N) and the mixture absorbance was read after 10 min of reaction at 530 nm. For the determination of anthocyanin contents, the molar extinction coefficient of cyanidin-3-glucoside (C3G: $\varepsilon= 26900$ $L.mol^{-1}.cm^{-1}$) was

used. The result was expressed as milligrams of cyanidin-3-glucoside equivalent per 100 grams of fresh weight (mg C3GE/100 g FW).

Ascorbic acids content

Ascorbic acid (AA) of figs was extracted by stirring 1.5 g of the sample with 10 mL of oxalic acid (1%) in darkness for 30 min. The solution was centrifuged at 1700 × g for 10 min, the supernatant was filtered and recovered. The amount of AA was assessed according to Meena *et al*. (2017). An aliquot of 100 µL of the upper fraction of extract was added to 900 µL of DCIP (2-6 dichlorophenol indolphenol). After 15 seconds of reaction, the absorbance was measured at 515 nm. Ascorbic acid content was calculated by a calibration curve prepared using ascorbic acid as standard ($y=-0.0069x+0.5654$; $R^2=0.984$) and was expressed as milligrams ascorbic acid equivalent per 100 grams of fresh weight (mg AAE/100g FW).

Carotenoid content

The carotenoids were extracted according to the method described by Sass-Kiss *et al*. (2005). An aliquot sample of 0.8 g was added to 10 mL of solvent mixture (hexane/acetone/ethanol; 2/1/1, V/V/V). After 30 min of shaking in the darkness, the hexane phase was recovered for spectrophotometric absorbance. The absorbance of hexane phase extract, containing carotenoids, was read at 450 nm. The results were determined using a calibration curve and β-carotene as standard ($Y=23.602\ x$; $R^2=0.996$) and the carotenoids content was calculated as milligrams of β-carotene equivalent per 100 grams of fresh weight (mg βCE/100 g FW).

Antioxidant activities

Evaluation of free radical scavenging activity

The antiradical activity of fig extracts against DPPH radical was evaluated according to Brand-Williams *et al*. (1995). Two hundred microliters of extract were mixed with 1000 µL of DPPH solution (60 µM). After 30 min of incubation at room temperature and in darkness, the absorbance was measured at 515 nm. The free radical scavenging activity was calculated using a calibration curve carried out with gallic acid as standard, and the antioxidant activity was expressed as milligrams gallic acid equivalent (mg GAE/100g FW).

Evaluation of ferrous ion chelating activity

The ferrous ion chelating activity (FIC) of figs extract was determined by the method described by Wang *et al*. (2008). An aliquot of 25 µL ferrous chloride (2 mM) was added to 250 µL of fig extract and 800 µL of distilled water. The mixture was incubated for 5 min, and then the reaction was initiated by the addition of 50 µL of ferrozin solution (5 mM). The absorbance of the complex ferrozine-Fe^{2+} was measured at 562 nm. FIC was calculated using the following equation (Eq. 1):

$$FIC(\%)=\left[1-\frac{A1-A2}{A0}\right]*100 \qquad (1)$$

where FIC is the ferrous ion chelating activity, A0 is the absorbance of the mixture with the extraction solvent instead extract, A1 is the absorbance of the mixture

containing extract and A2 is the absorbance of the mixture without the presence of ferrozin.

Statistical analysis

The data were performed using Statistica software (Statistica® 7.1). Results were compared by ANOVA/MANOVA with LSD Fisher test (Least Significant Difference) in order to determine significant differences ($P<0.05$). All results were expressed as the mean of triplicate ± standard deviation. The relationship among all parameters in fresh figs was described as Pearson correlation coefficient and a significant degree was considered at P-value of 0.05 as statistically significant, and at 0.01 or 0.001 for highly and very highly significant, respectively.

Results and discussion

Physicochemical parameters

The values of pH and total soluble solids were shown in Table 1. Initial values of pH for figs of AB and HA cultivars were 5.38 and 4.42, respectively. The initial measured pH values were consistent with those found by Villalobos *et al*. (2015b) with a pH value of 5.44 for fresh figs, but lower than those reported by Pereira *et al*. (2015) at pH 5.9.

pH values of AB showed significant ($P<0.05$) decrease during 5 days of storage, then remained steady at the later stage of conservation, either with the presence or absence of ethylene absorbent, whereas, this parameter was increased in P batches and remained steady in PE treatment for HA cultivar.

The effect of MAP conservation on pH value was controversial. The decrease of pH values could be due to the formation of carbonic acids resulting from the reaction of accumulated H_2O and CO_2 on the fruit surface during storage (Banda *et al*., 2015). A decline of pH during modified atmosphere packaging was also observed by Villalobos *et al*. (2014) on fresh figs. On the other hand, Bouzo *et al*. (2012) found that pH was not affected during MAP figs storage.

The initial values of TSS were ranging from 15 to 25°Bx for AB figs, and from 13 to 28°Bx for HA figs (Table 1). Our initial values were in agreement with those found by Simsek *et al*. (2017) and lower than those reported by Crisosto *et al*. (2010) for fresh figs. The difference of obtained values with the literature was probably due to the radiation levels reached in the orchard (Villalobos *et al*., 2015b).

TSS results during MAP storage showed a significant ($P<0.05$) decreased especially for figs treated with ethylene absorbent, except for P1 of AB and for HA cultivars after 5 days of conservation (Table 1). This decline could be explained by the conversion of soluble sugars into organic acids such as citric acid (Bhatia *et al*., 2013). The decline of TSS during PE storage could be explained by the fact that when ethylene is absorbed by $KMnO_4$ the breakdown rate of cell wall polysaccharides (starch particularly) will decrease, and then, the increase of TSS

level is retarded (Bashir *et al*., 2003). Our results were also in agreement with Akbudak *et al*. (2004) who reported a decrease of TSS from 10.50 to 9.18 at the end of MAP storage of peach and nectarine fruits.

Table 1. Results of pH and total soluble solids (TSS) during MAP storage (P) and MAP with $KMnO_4$ (PE) during 5 and 10 days for AB (*Abakour-aberkane*) and HA (*Tahayounte*) cultivars.

		AB		HA	
Mode of conservation	**Storage time (Day)**	**pH**	**TSS (°Bx)**	**pH**	**TSS (°Bx)**
Control	0	5.38±0.13^{a}	24.33±1.15^{a}	4.42 ±0.19^{b}	23.46±2.68^{a}
Batch P1	5	4.51±0.36^{b}	25.76±0.66^{a}	4.71±0.27^{a}	28.83±4.47^{a}
Batch P2	10	4.73±0.22^{b}	19.73±1.10^{b}	4.61±0.24^{ab}	22.66±4.61^{ab}
Batch PE1	5	3.97±0.11^{c}	15.73±1.01^{c}	4.05±0.34^{c}	20.73±5.70^{b}
Batch PE2	10	4.35±0.16^{bc}	16.70±0.43^{c}	4.16±0.04^{bc}	13.20±0.20^{c}

Values are means ± SD of three samples analyzed in triplicate; results in the same column with different letters are significantly different (P<0.05, a>b>c).

Contents of bioactive compounds

Total phenolic contents

The initial values of total phenolic contents (TPC) were 316.03 and 493.42 mg GAE/100g FW for the yellow (HA) and the dark (AB) figs, respectively (Table 2). The initial values of TPC were in accordance with Bachir Bey and Louaileche (2015) and Ouchemoukh *et al*. (2012) with TPC values of 482.62 and 470 mg GAE/100g FW, respectively, for Algerian figs but higher than those obtained by Harzallah *et al*. (2016) at amount of 74.10 mg GAE/100g FW for Tunisian ones. These differences could mainly due to genetic variations, geographical areas, climatic factors, and ripening stages (Gull *et al*., 2012). The phenolic profiles of figs are mainly represented by phenolic acids belonging to derived benzoic acid (gallic and syringic acids) and derived cinnamic acids (chlorogenic, ferulic and caffeic acids) (Arvaniti *et al*., 2019).

TPC remained steady at 5 days of MAP storage of AB cultivar. A significant decrease ($P<0.05$) of phenolic compounds during storage for both cultivars were observed, except for P1 of AB cultivar after 5 days of conservation. The decrease of TPC was more pronounced for batches treated with $KMnO_4$: from 16 to 30% of loss for AB cultivar, while HA cultivar showed no significant changes ($P>0.05$) between treated samples. The diminution of TPC could be explained by the effect of high CO_2 and low O_2, that might retard the activity of key enzymes involved in the biosynthesis pathway of phenolic compounds (Guilleń *et al*., 2015). Same results were obtained by the previous authors who reported that storage under MAP delays the accumulation of phenolic compounds of figs fruits.

Total flavonoid content

The initial flavonoid contents of AB and HA cultivars were 48.31 and 40.39 mg QE/100g FW, respectively (Table 2). Initially recorded flavonoid contents were similar with those reported by Kamiloglu and Capanoglu (2015) who found that purple fresh figs had higher amount of flavonoids than yellow figs. Arvaniti *et al*. (2019) reported that cyanidin-3-O-glucoside and cyanidin-3-O-rutinoside are the main identified flavonoids in figs belonging to the anthocyanidins family, most likely present in AB figs.

TFC of AB cultivar were slightly decreased for P batches stored for 5 and 10 days, but PE were strongly affected with a decline about 38%. For HA figs, flavonoids contents of both treated samples were significantly decreased by 1/3 reaching about 26 mg QE/100g FW at 5 days of conservation. However, there were no significant changes ($P>0.05$) between treated samples of HA cultivar during storage. This decrease was related to the diminution in overall levels of phenolic compounds, probably due to oxidation and/or condensation of some phenolic acids leading to form a complex of phenolic compounds during ripening (Gull *et al*., 2012).

Total anthocyanin content

The initial total anthocyanin content of dark cultivar was ten-fold higher than yellow one with the values of 41.39 and 4.12 mg C3GE/100g FW, respectively.

The high anthocyanin content of AB was due to the black color of the fig skin which is rich in anthocyanins; whereas the HA cultivar (yellow) has a low concentration. Caliskan and Polat (2011) observed that dark-skinned figs had 10 to 15-fold anthocyanins than light ones. Our results were lower than those of Turkish fresh figs (Kamiloglu and Capanoglu, 2015) and higher than those obtained by Bachir Bey and Louaileche (2015). The differences between our initial results and literature data were due to many factors such as genetic variation, climatic effect and light exposure (Caliskan and Polat, 2011).

During storage, anthocyanin contents were increased for batch stored under MAP at 5 days for AB figs and for MAP associated with ethylene absorbent of HA figs. Fruits maturation process could explain this increase. In fact, during the first storage period, the CO_2 concentration emitted by the figs had not reached the threshold required for the conservation, and the respiration of the fruits still continues. However, at 10 days of AB-MAP storage, a decrease of anthocyanins was denoted, and this could be due to the delay of the maturation caused by high CO_2 and low O_2 concentrations in the package. In addition, further degradation was manifested due to the instability of these compounds. Guilleń *et al*. (2015) claimed that MAP retards the increase of anthocyanin contents during storage.

Anthocyanin contents showed a decrease during AB-PE conservation and this could be due to the delaying of fruits maturation caused by the absence of ethylene which is absorbed by $KMnO_4$. HA figs, which had low anthocyanin contents, did not express high considerable variations during storage, except for PE batches. The effect of modified atmosphere packaging on anthocyanin contents could differ

from fruit to another. Indeed, Banda *et al*. (2015) suggest that MAP can retard anthocyanins degradation on pomegranate arils.

Table 2. Results of bioactive compounds and antioxidant activities MAP storage (P) and MAP with $KMnO_4$ (PE) during 5 and 10 days for AB (*Abakour-aberkane*) and HA (*Tahayounte*) cultivars

Mode of conservation	Storage (Day)	TPC (mg/GAE 100g)	Flavonoids (mg QE/100g)	Anthocyanins (C3GE/100g)	Ascorbic acid (mg AAE/100g)	Carotenoids (mgβCE /100g)
AB cultivar						
Control	**0**	493.42±6.46^{a}	48.31±0.92^{a}	41.39±0.35^{b}	11.29±1.51^{a}	2.83±0.13^{c}
Batch P1	**5**	484.16±8.43^{a}	46.44±0.62^{a}	54.21±0.07^{a}	10.93±0.41^{a}	3.41±0.04^{b}
Batch P2	**10**	415.00±4.15^{b}	42.29±1.91^{b}	33.40±0.13^{c}	9.85±0.34^{ab}	3.59±0.07^{ab}
Batch PE1	**5**	413.53±4.34^{b}	28.86±1.33^{d}	25.48±0.15^{d}	9.85±0.34^{ab}	3.68±0.29^{a}
Batch PE2	**10**	341.88±6.59^{c}	31.36±0.92^{c}	25.01±0.23^{e}	8.80±0.96^{b}	3.44±0.05^{ab}
HA cultivar						
Control	**0**	316.03±1.24^{a}	40.39±2.64^{a}	4.12±0.25^{b}	8.10±0.34^{a}	9.23±0.03^{d}
Batch P1	**5**	266.35±3.37^{b}	25.61±1.38^{b}	3.95±0.09^{b}	7.34±0.73^{b}	10.90±0.07^{a}
Batch P2	**10**	276.90±1.59^{b}	27.99±1.12^{b}	3.43±0.23^{c}	6.26±0.19^{c}	8.33±0.10^{e}
Batch PE1	**5**	273.38±13.15^{b}	26.38±1.55^{b}	4.73±0.07^{a}	7.13±0.59^{b}	10.76±0.03^{b}
Batch PE2	**10**	271.01±9.53^{b}	25.56±1.02^{b}	4.44±0.12^{a}	5.93±0.13^{c}	9.94±0.04^{c}

Values are means ± SD of three samples analyzed in triplicate; results in the same column for each cultivar with different letters are significantly different (P<0.05, a>b>c>d).

Ascorbic acid content

The initial content of total ascorbic acid for AB cultivar was higher than HA one with values of 11.29 and 8.10 mg AAE/100g FW, respectively. Our initial results were in agreement with those reported by Pereira *et al*. (2017) on figs, and in disagreement with results reported by Irfan *et al*. (2013).

There were no significant losses of AA content during AB storage, except for PE2 figs. A significant decrease (P<0.05) of AA during MAP with the presence or absence of ethylene absorbent were observed for HA cultivar (Table 2). Ghasemnezhad *et al*. (2011) explained the reason of the decline of AA in bell pepper fruits during ripening as the fact of oxidative phenomenon process, and the AA is required in this phase because of its antioxidant propriety. The decrease of AA in MAP with ethylene absorbent was probably due to $KMnO_4$, known as a strong oxidizing agent. A slight decline of AA in AB cultivar during MAP can probably be explained by the accumulation of organic acids, which was confirmed by the decrease for pH as indicated in Table 1. This acidity might have a protective effect against the oxidation of AA (Irfan *et al*., 2013). Similar decreasing of AA was observed for guava fruit during ripening (Bashir *et al*., 2003).

Carotenoid contents

Carotenoid contents of HA figs was three fold higher than that of AB with 9.23 and 2.83 mg βCE/100g FW, respectively (Table 2). Initial values of fig carotenoids were lower than those reported by Ouchemoukh *et al*. (2012). Carotenoids were significantly increased (P<0.05) during storage under MAP, associated or not with ethylene absorbent for AB fig. For HA, the results showed that carotenoid contents

were increased at the early stage of storage, however they were significantly decreased at the end of the conservation. The increasing of carotenoids was probably due to the atmosphere packaging which did not reach the adequate concentration of gases to conserve the freshness of figs. The decrease of carotenoids occures during the ripening process of figs. In the large literature, there is scarcity in the studies that deal with the effect of storage under MAP on carotenoid contents of fresh figs.

Antioxidant activity

Free radical scavenging activity

Initial values of free radical scavenging activity were about 58 mg GAE/100g FW for both cultivars (Figure 1). A significant decrease ($P<0.05$) of DPPH scavenging power was observed for all batches of HA figs and for PE2 treatments of AB cultivar at 10 days of conservation. This decline was more pronounced for HA cultivar with an overall reduction of 76%. The results were higher than those obtained by Selcuk and Erkan (2014) who reported the increase of EC_{50} values from 32.61 to 38.58 mg/mg DPPH during the storage of sweet pomegranates under modified atmosphere packaging. The decrease of FRS was different to that obtained by Guilleń *et al*. (2015) who concluded that the storage of figs under MAP had no negative effect on total antioxidant activity.

A decline in antiradical activity could be linked to the decrease of phenolic compounds and flavonoids of figs during storage (Bashir *et al*., 2003; Gull *et al*., 2012). According to Arvaniti *et al*. (2019), the decrease in antioxidant activity is probably related to the decline in phenolic acids (gallic, caffeic, and chlorogenic acids) and flavonoids (quercetin, catechin and rutin) which are responsible for the antioxidant activity.

The decrease of free radical scavenging activity during ripening was obtained by Benchikh *et al*. (2014) in carob, and probably due to the decline in analyzed bioactive compounds occurring during fruit development.

The decrease of antioxidant activity during PE storage was due to ethylene absorbent and ripening process. In fact, $KMnO_4$ is recognized as an oxidizing agent that was combined with the reactive oxygen species generated during maturation might explain the decrease of antioxidant activity (Jimenez *et al*., 2002).

Ferrous ion chelating activity

Fig extracts demonstrated a considerable ferrous ion chelating activity (FIC) for no treated AB and HA cultivars which were 59.61% and 48.36%, respectively. The results showed a significant decrease ($P<0.05$) in FIC for dark fig (AB) during storage ranging from 4 to 18 %, while this activity remained steady for yellow fig (HA) with the exception of PE1 (Figure 2). These results agree partially with those reported by Benchikh *et al*. (2014) who observed a decrease of FIC during carob ripening.

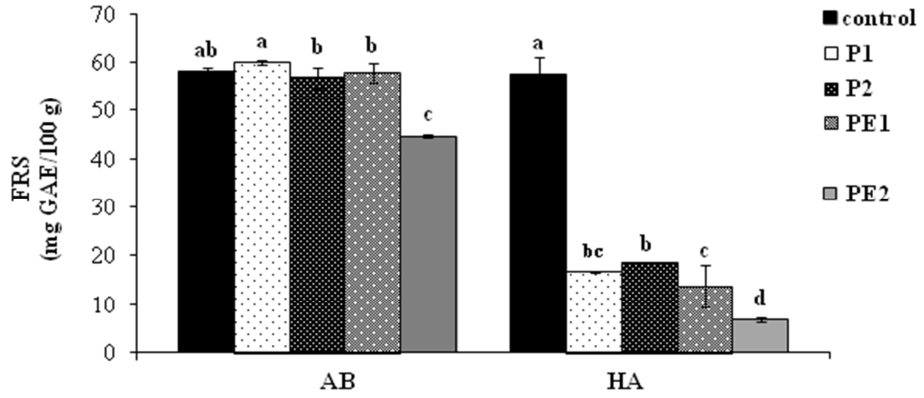

Figure 1. Free radical scavenging activity (**FRS**) of *Abakour-aberkane* (**AB**) and *Tahayounte* (**HA**) cultivars during cold storage

P1: *MAP at 5 days,* ***P2:*** *MAP at 10 days,* ***PE1:*** *MAP with $KMnO_4$ at 5 days,* ***PE2:*** *MAP with $KMnO_4$ at 10 days, results with different letters for each cultivar are significantly different (P<0.05, a>b>c>d).*

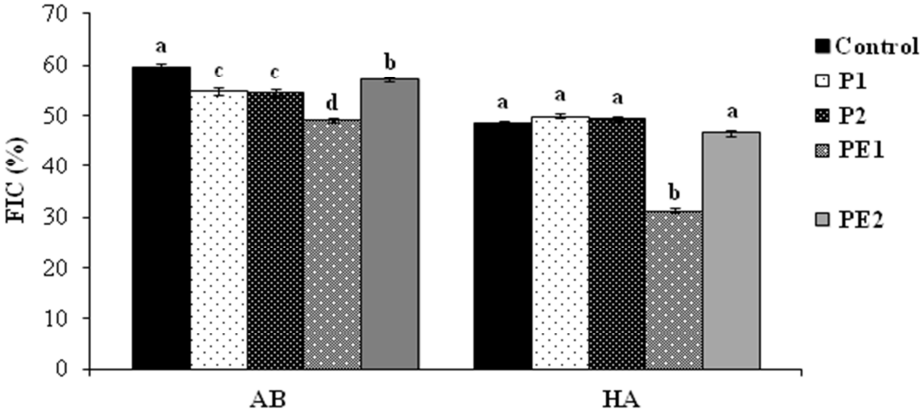

Figure 2. Ferrous ion chelating activity (**FIC**) of *Abakour-aberkane* (**AB**) and *Tayahounte* (**HA**) cultivars during cold storage

P1: *MAP at 5 days,* ***P2:*** *MAP at 10 days,* ***PE1:*** *MAP with $KMnO_4$ at 5 days,* ***PE2:*** *MAP with $KMnO_4$ at 10 days, results with different letters for each cultivar are significantly different (P<0.05, a>b>c>d).*

Correlation among the bioactive compounds and antioxidant activities

The results given in Table 3 showed that bioactive compounds and antioxidant activities had linear positive correlations, except between the results of flavonoids and ascorbic acid contents and FIC results, where no significant correlation was noticed. Highly significant correlations (P<0.01) were observed between bioactive compounds (total phenolics, flavonoids, anthocyanins, and ascorbic acid). These later presented highly significant correlations (P<0.01) with radical scavenging activity, except between anthocyanins and FRS results, where the correlation was just significant (P<0.05). This is mainly explained by the high reactivity of these compounds toward oxidative agents. Positive correlations of bioactive compounds

with antioxidant activity (FRS) were similar with those obtained by Bachir Bey and Louaileche (2015).

Table 3. Correlation between bioactive compounds and antioxidant activities.

	TPC	Flavonoids	Anthocyanins	Ascorbic acid	FRS
Flavonoids	0.84**				
Anthocyanins	0.95***	0.78**			
Ascorbic acid	0.97***	0.82**	0.92**		
FRS	0.84**	0.81**	0.75*	0.89**	
FIC	0.63*	ns	0.63*	ns	ns

FRS: free radical scavenging activity; FIC: ferrous ion chelating activity; results were expected as statistically significant (*P<0.05); highly significant (**P<0.01), or very highly significant (***P<0.001); ns: non-significant.

Visual appearance of fruits

The visual appearance of figs during different conservation modality was shown in Figure 3. AB cultivar packed under MAP combined to ethylene absorbent at 10 days of storage seemed to lose its firmness which probably due to the cell wall disassembly during ripening in line with Villalobos *et al*. (2014) findings. Fruits conserved in P2 batch for AB cultivar seemed to lose their color (significant decreased (P<0.05) of anthocyanins confirmed the visual appearance). MAP treatment of HA cultivar conserved during 5 and 10 days in P1 and P2 (absence of ethylene absorbent) seemed to conserve its firmness and color compared to PE1 and PE2 (presence of ethylene absorbent), and the same observation was noticed for AB cultivar.

Conclusions

Our results showed that modified atmosphere packaging technique allows the extension of shelf life of figs for 10 days either for AB and HA cultivars at cold storage (4°C). Modified atmosphere packaging limits significantly (P<0.05) the ripening process by retarding the decrease of bioactive compounds (phenolic compounds, flavonoids, anthocyanins, carotenoids, and ascorbic acid) and maintained antioxidant activities during cold storage. It has been observed that fig conservation under MAP had better storage ability for extending fruits shelf life than modified atmosphere packaging combined with ethylene absorbent. Significant and positive correlations were observed between bioactive compounds and antioxidant activities. Our results demonstrated also that the effect of conservation modality depends on the cultivars; AB and HA cultivars had different behavior towards conservation. The use of microperforated punnets to create a modified atmosphere packaging seems to be a simple, helpful and feasible method for retarding the ripening of figs and then to contribute maintaining the freshness of figs from threatened cultivars. Further studies are needed like the evaluation of nutritional values, fruit firmness, and accountant of microbial growth of conserved

fruit. The study of other cultivars is required to confirm the maintenance of bioactive compounds during storage, in order to promote commercialization over a long period.

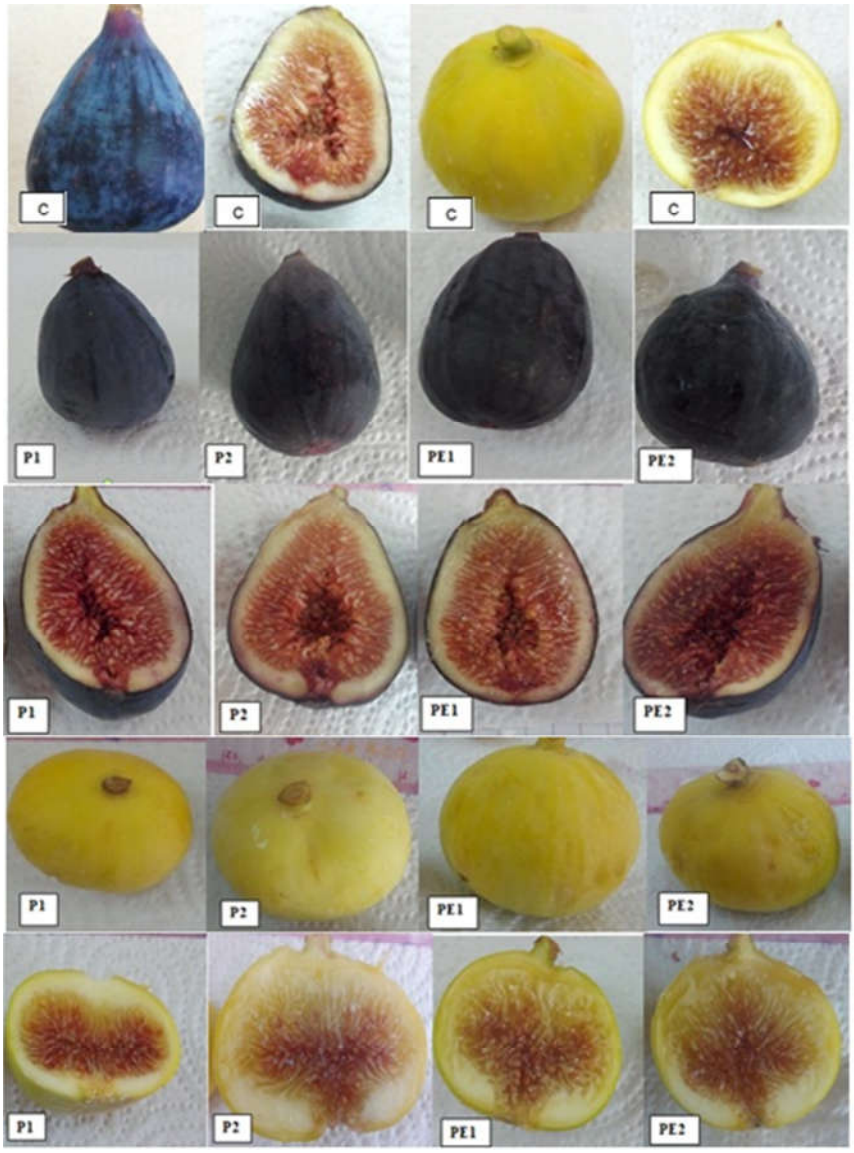

Figure 3. Visual appearance of whole and transversally cut figs under different storage conditions for the dark (AB) and yellow (HA) cultivars *C: Control, P1: MAP at 5 days, P2: MAP at 10 days, PE1: MAP with $KMnO_4$ at 5 days, PE2: MAP with $KMnO_4$ at 10 days.*

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Conflict of interest

The authors declare that the present work was conducted in the absence of any commercial, financial, personal or other relationships that could be construed as a potential conflict of interest.

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