Original article

Effects of innovative packaging materials on apricot fruits (cv Tom Cot®)

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Effects of innovative packaging materials on apricot fruits (cv. Tom Cot®).

Abstract – **Introduction**. Innovation in the management of perishability/freshness is an essential theme of the future fruit sector, not only for commercial and distribution systems but also for production. Plastic films with modified atmospheres represent a postharvest technology that can be used to store stone fruits, such as apricots, that have a short shelf life when maintained in a normal atmosphere under cold conditions. The aim of our work was to evaluate the effect of several packaging materials on the postharvest quality of apricot fruits stored for 21 days by considering the most important qualitative traits. **Materials and methods**. Modified atmosphere technology with different packaging materials was used to store apricot fruits cv. Tom Cot® at (+1 ± 0.5) °C and 90–95% relative humidity (RH). Different passive modified atmosphere packaging (MAP) conditions were developed because of the interaction between fruit respiration and the different oxygen and carbon dioxide barriers of the films. The effects of MAP were evaluated on the postharvest quality of the fruits by monitoring the headspace gas composition, weight loss, fruit flesh firmness (FFF), total soluble solids content (TSS), titratable acidity (TA) and skin colour. **Results and discussion**. Changes in packaging headspace gas composition were observed for all films used, but only multilayer films and biodegradable film maintained the MAP conditions until the end of storage. Wrapped fruits lost less weight than fruits maintained under normal conditions; in particular, multilayer films maintained the highest FFF values after 21 days. The biodegradable film exhibited good performance in terms of maintaining the CO_2 and O_2 equilibrium inside the baskets by balancing the fruits' respiration and the film's permeability. Traditional plastic materials, such as multilayer films, and more sustainable films, such as the biodegradable film used in our study, can be successfully employed to store apricot fruits cv. Tom Cot® for up to 21 days in passive MAP conditions.

Italy / *Prunus armeniaca* / fruits / keeping quality / film (packaging) / controlled atmosphere storage / quality

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Effets de matériaux d'emballage innovants sur la conservation de l'abricot (cv. Tom Cot®).

Résumé – **Introduction**. L'innovation dans le contrôle de l'altérabilité/fraîcheur est un thème essentiel du secteur des fruits du futur, non seulement pour les systèmes commerciaux et de distribution, mais également pour leur production. Les films plastiques avec atmosphères modifiées représentent une technologie après récolte qui peut être utilisée pour stocker des fruits à noyau, tels que les abricots, qui ont une courte durée de vie lorsque maintenus dans une atmosphère normale en conditions réfrigérées. Le but de notre travail a été d'évaluer l'effet de plusieurs matériaux d'emballage sur la qualité après récolte d'abricots cv. Tom Cot® stockés pendant 21 jours en s'intéressant aux caractéristiques qualitatives les plus importantes. **Matériel et méthodes**. La technologie de l'atmosphère modifiée adaptée à différents matériaux d'emballage a été utilisée pour stocker des abricots cv. Tom Cot® à (+1 ± 0.5) °C et 90–95 % d'hygrométrie. Différentes conditions d'emballage en atmosphère modifiée (EAM) ont été développées en raison de l'interaction entre la respiration du fruit et les différentes barrières à l'oxygène et au dioxyde de carbone des films. Les effets des EAM ont été évalués sur la qualité après récolte des fruits en évaluant la composition du gaz de l'espace libre dans l'emballage, la perte de poids, la fermeté du fruit, le teneur en solides solubles totaux, l'acidité titrable et la couleur de la peau. **Résultats et discussion**. Des changements de la composition en gaz dans l'espace libre des emballages ont été observés pour tous les films utilisés, mais seuls les films multicouches et le film biodégradable ont maintenu les conditions d'EAM jusqu'à la fin de la période de stockage. Les fruits enveloppés ont perdu moins de poids que des fruits maintenus en conditions normales ; en particulier, les films multicouches ont permis d'obtenir les valeurs de fermeté du fruit les plus élevées après 21 jours. Le film biodégradable a été performant pour maintenir l'équilibre CO_2/O_2 à l'intérieur des boites en équilibrant la respiration du fruit et la perméabilité du film. Des matières plastiques traditionnelles, tels que les films multicouches, et des films plus durables, tel que le film biodégradable utilisé dans notre étude, peuvent être utilisés avec succès pour conserver des abricots cv. Tom Cot® jusqu'à 21 jours en conditions passives de stockage en atmosphère modifiée.

Italie / *Prunus armeniaca* / fruits / aptitude à la conservation / film (emballage) / stockage en atmosphère contrôlée / qualité

1. Introduction

Apricots (*Prunus armeniaca* L.) are stone fruit; their production plays a key role in the agricultural sector of the European market. In Europe, apricot production remains concentrated in Mediterranean-type areas; Italy is the largest producer in the EU-27, followed by France, Greece and Spain[1]. Fruits are generally destined for fresh consumption, and current advances in logistics and packaging technologies allow the consumption of fruits even in distant markets. As the market for fresh produce is growing steadily, the need to guarantee quality is increasing.

Shelf life is closely related to fruit variety, and apricots, which are the most widely marketed stone fruit, are highly perishable. In particular, one of the most important factors limiting apricot quality is the reduction of pulp hardness [1], which influences the commercialisation period before the product reaches the consumer.

Apricots are climacteric fruits; they are occasionally harvested in the early stages of development (preclimacteric) to prevent deterioration problems in the postharvest supply chain [2].

Quality indices include fruit size, shape and absence of defects. Apricots with a soluble solid content higher than 10 °Brix, low acidity (0.7–1.0%) and high pulp hardness (9–13.5 N) are considered "ready to eat" [3].

Modification of the atmosphere and the related packaging technology (MAP) can be selectively used in postharvest handling to improve the shelf life of fresh fruits and vegetables with good results [4].

Alteration of the atmosphere around fruits during postharvest by decreasing O_2 levels and increasing CO_2 levels can increase the storage life of different produce, and refrigeration is a key tool for extending the commercial life of stone fruit [5].

Modified atmosphere (MA) technology can be more flexible than controlled atmosphere (CA) methods for extending the benefits of increased CO_2 in improving the shelf life of fruit during distribution and storage [6]. The use of a MA is a dynamic process that includes an alteration of the gases within the packaging [7]. The modified atmosphere extends the benefits of an increased CO_2 preservation environment throughout the supply chain [6]; it is influenced by the permeability of the film to the gas, the rate of respiration of the fruits and temperature [8–10]. Storing apricots in concentrations between (10 and 15) kPa of CO_2 has been found to decrease decay development and gel breakdown. Two modified atmosphere packaging (MAP) treatments that produced (13 to 15) kPa CO_2 and either 3 kPa or 10 kPa O_2 prevented decay development in 'Canino' apricots after 35 days of storage and 4 days at 20.8 °C, whereas control fruits exhibited 30% decay [11].

Polymeric films for MAP are most often found in flexible package structures and, although an increasing choice of packaging materials is available to the industry, polyvinyl chloride (PVC), polyethylene terephthalate (PET), polypropylene (PP) and polyethylene (PE) are the typical polymers used to store fruits [12]. For commercial and mechanical reasons, the film must be (15 to 100) µm thick [13].

The evolution of the headspace gas composition and ethylene in three varieties of apricot stored at 10 °C under four microperforated films (30-µm thick) was studied. As the film permeability increased, the CO_2 concentration at equilibrium decreased and the O_2 concentration increased [14].

Recently, a commercial multilayer film used for MAP performed well in maintaining the quality for the cold storage period for up to 20 days in old Italian plum cultivars [15]. The use of PVC to store mango fruits at room temperature allowed the skin and pulp colour to be maintained for 13 days, compared with 9 days for unpackaged fruits [16].

The properties of these materials that make them ideal for packaging include the weldability of the packs and their antifogging characteristic. However, the introduction of environmentally friendly materials and new filming processes, such as coextrusion, allows the use of biodegradable

[1]FAOSTAT data, FAO, Roma, Italy, http://apps.fao.org/; seen in 2011.

polymers from renewable sources as alternatives to petroleum-based polymers [17]. Studies have compared the effects of biodegradable laminates and films on the quality of fresh produce [18, 19]; the shelf life of peach and cherry tomatoes improved with use of polylactic acid when compared with conventional oriented polypropylene (OPP) [20] and the qualitative characteristics of raspberry fruits stored in MAP were better maintained with biodegradable film than with polypropylene film [21]. However, bio-based materials have not yet been evaluated for apricot fruits.

Packaging attributes can affect the decision of consumers to purchase fresh produce in general, and the successful commercialisation of fresh produce is related to the use of bio-materials [22]. Thus, the aim of our study was to evaluate the effects of MAP on the storage of apricot fruits (cv. Tom Cot®) by evaluating the performance of different films used in unit flowpacks that yielded "ready-to-eat" fruit.

2. Materials and methods

2.1. Fruit samples

Fresh ripe apricots (*Prunus armeniaca* L.) of the Tom Cot® cultivar were obtained from the Agrifrutta Soc. Coop. S.R.L. (Piedmont, Italy) commercial orchard at the ripe stage of maturity (3.0–2.5 $kg \cdot cm^{-2}$ of pulp hardness). Apricots were picked by hand at the end of June and immediately transferred to the laboratory under cold conditions [(4 ± 1) °C]. Damaged and mouldy fruits were eliminated (by hand) prior to analysis. The different storage treatments were initiated approximately 3 h after harvest.

2.2. Packaging and storage conditions

The apricots were packaged into rigid polyethylene terephthalate (PET) trays containing 0.500 kg of fruit each. Each tray (9.5 cm × 16 cm × 8 cm) was hermetically sealed with a flowpack machine using five different films (treatments). The following materials were used:

– Treatment F1: multilayer film obtained from coextrusion of PET, ethylene vinyl alcohol (EVOH) and polyethylene (PE) (90-μm thick).

– Treatment F2: multilayer film obtained from coextrusion of PET, EVOH and PE (65-μm thick).

– Treatment F3: polypropylene (Trepack, Italy), continuous, flexible, thermoformable and commercial film (25-μm thick).

– Treatment F4: biodegradable film (Mater-Bi, Novamont, Italy).

– Treatment F5: macro-perforated film in polypropylene (Trepack, Italy) with 6-mm-diameter holes and a transparent and commercial film. The film has a typical isotactic structure (in which the substituents are arranged on one side) and high crystallinity (25-μm thick).

The oxygen (O_2) and carbon dioxide (CO_2) film permeability according to ASTM F 2622-08 and ASTM F 2476-05 measured at 23 °C and 50% relative humidity (RH) is indicated (*table I*). The water vapour barrier of the multilayer films (F1 and F2 treatments) and the polypropylene film (F3 treatment), as suggested by Van Tuil *et al.* [23], is classified as a high barrier, whereas for the biodegradable film (F4 treatment), the water vapour transmission rate (WVT) of 147 $cm^3 \cdot m^{-2}$ for 24 h was directly provided by the supplier.

A set of trays was left unpackaged and used as the control. For the flowpack equipment, an electronic horizontal wrapping machine (Taurus 700, Delphin, Italy), including a take-up reel with translational movement of the clamping jaws, was used. The gas composition inside the packages changed from the atmospheric value (0.2 kPa CO_2 / 21.2 kPa O_2) because of the gas permeability of the film and apricot fruit respiration (passive MAP).

All fruits were stored at (1 ± 0.5) °C in a cold room held at 90–95% RH for 21 days.

2.3. Sampling method for analysis

The gas analysis and quality control were performed at the end of each storage period [(7, 14 and 21) days], and, for each treatment, three random baskets were used

(1.5 kg of apricot fruit). The headspace composition analysis was performed on whole baskets. The fruit flesh firmness, total soluble solids content and fruit colour were obtained for 30 fruits. Fifteen apricots per treatment were pressed at 20 °C to obtain juice to measure the titratable acidity (TA). Three replicates per measurement were used. Three lots were used to determine the quality properties at harvest (0 days).

2.4. Methods and analysis

2.4.1. Headspace gas composition

The carbon dioxide and oxygen in the headspace space of the packaging were measured using a CO_2 and O_2 analyser (PBI Dansensor, Italy). The composition values were measured over the entire trial period. To prevent modifications in the headspace gas composition caused by gas sampling, the same air volume was maintained in the packages across the trial period, as the analyser introduced the same quantity of air that it removed for the analyses. To prevent gas leakage during measurement, an adhesive septum was placed on the package surface. The calibration was performed with air [24]. The results were expressed as an average of three replicates.

2.4.2. Fruit quality parameters

The weight (water) loss of each apricot basket was measured using an electronic balance (SE622, WVR Science Education, U.S.A.) with an accuracy of 10^{-2}. The weight of each basket was recorded at harvest and at the end of each storage period. The weight loss was expressed as the percent loss of the initial weight.

The fruit flesh firmness was measured using an Effegi hand-held penetrometer (Facchini, Alfonsine, Italy) with a 7.9-mm-diameter plunger in accordance with standard industry practice. Two measurements were made on opposite sides of the fruit and averaged. No skin was removed from each measurement site prior to the measurements, which were reported in $kg \cdot cm^{-2}$.

The total soluble solids content was measured using a digital pocket refractometer (Mod. PR-101, Atago, Tokyo, Japan) calibrated at 20 °C to 0% with distilled water. The prism surface and light plate were washed and dried with clean soft tissue paper between readings. Two readings were taken from each fruit and averaged. The values were expressed as °Brix at 20 °C.

The titratable acidity was determined by automatic titration (Titrino plus 484, Metrohm, Switzerland) with 0.1 N NaOH to an end point of pH 8.1 using 5 mL of juice diluted in 25 L of distilled water.

The colour was evaluated just after harvest and again after each storage period of (7, 14 and 21) days. The colour was measured on the side of a slightly flattened whole fruit using a tristimulus colour analyser

Table I.
Characteristics of film used for modified atmosphere packaging to store apricot fruit cv. Tom Cot®.

Treatment	Film gas permeability at 23 °C and 50% HR ($mmol \cdot cm^{-1} \cdot cm^{-2} \cdot h^{-1} \cdot kpa^{-1}$)		Film thickness (μm)
	O_2 (ASTM F2622-08)	CO_2 (ASTM F2476-05)	
F1: Multilayer film with 90-μm-thick PE	6.738E-13	9.430E-12	90
F2: Multilayer film with 65-μm-thick PE	1.752E-12	6.811E-12	65
F3: Polypropylene film	6.241E-13	1.979E-12	25
F4: Biodegradable film	9.756E-13	1.907E-11	25
F5: Macro-perforated film in polypropylene	–	–	25

Multilayer film was obtained from coextrusion of polyethylene terephthalate (PET), ethylene vinyl alcohol (EVOH) and polyethylene (PE).

(Chroma Meter, Model CR-200b, Minolta, Germany) equipped with a measuring head with an 8-mm-diameter measuring area. The analyser was calibrated to a standard white reflective plate and used CIE (*Commission Internationale de l'Eclairage*). The illuminant colour was recorded using the CIE L^*, a^*, b^* uniform colour space (CIE Lab), where L^* indicates lightness, a^* indicates chromaticity on a green (−) to red (+) axis and b^* indicates chromaticity on a blue (−) to yellow (+) axis. These values were used to calculate the chroma [$C^* = (a^{*2} + b^{*2})^{1/2}$], which indicates the intensity or colour saturation and the hue angle [$h° = \text{arctangent}(b^*/a^*)$], where 0° = red-purple; 90° = yellow; 180° = bluish-green and 270° = blue [25].

2.5. Statistical analysis

All statistics were performed using the SPSS software for Windows version 17.0. The data obtained were treated using a one-way analysis of variance (ANOVA), and the means were separated using Tukey's test ($P \leq 0.05$). It was possible to perform a parametric test for the percentages because the sample sizes were identical.

3. Results and discussion

The O_2 and CO_2 levels detected in the sample package headspace during storage showed that the apricot respiration and the different gas permeability of the films were able to create and maintain the modified atmosphere packaging conditions (*figures 1, 2*). The temperature, the fruit weight and the exchange area through the film were kept constant during the entire storage time, so the evolution of the internal atmosphere inside each basket was influenced and controlled by the interaction between the fruits' respiration and the film's permeability. The initial atmospheric composition (0.2 kPa CO_2 / 21.2 kPa O_2) in the baskets changed rapidly in all the treatments. From the harvest time, as expected, a decrease in the headspace O_2 concentration and an increase in the headspace CO_2 concentration were observed because of the fruit maturation process. In particular, a faster decrease in the headspace O_2 concentration and a faster increase in the headspace CO_2 concentration were observed during the first 7 days of storage as a consequence of high respiration activity. Packaging of apricot fruit in the two multilayer films (F1 and F2 treatments) concurrently produced similar CO_2 values; no significant differences were observed between the levels of the gas composition established in the two treatments because of the similar values of gas permeability of the film (*table I*). According to Pretel *et al.*, as the film permeability decreased, the CO_2 values increased [14]. In particular, the highest CO_2 values were obtained after 21 days of storage with the F1 (19.2 kPa) and F2 treatments (18.5 kPa) (*figure 2*).

The polypropylene film (F3 treatment) did not establish an acceptable modified

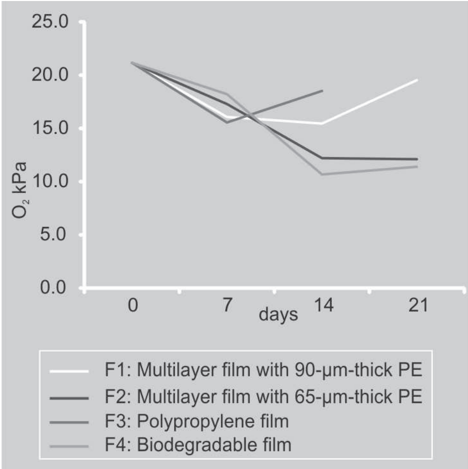

Figure 1.
Evolution of O_2 headspace gas composition of apricots cv. Tom Cot® stored in modified atmosphere packaging at + 1 °C. Multilayer film was obtained from coextrusion of polyethylene terephthalate (PET), ethylene vinyl alcohol (EVOH) and polyethylene (PE).

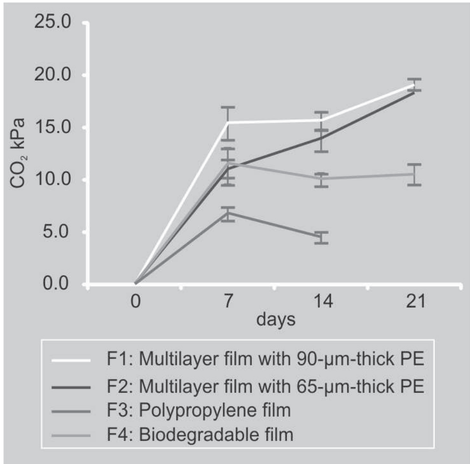

Figure 2.
Evolution of CO_2 headspace gas composition of apricots cv. Tom Cot® stored in modified atmosphere packaging at + 1 °C. Multilayer film was obtained from coextrusion of polyethylene terephthalate (PET), ethylene vinyl alcohol (EVOH) and polyethylene (PE).

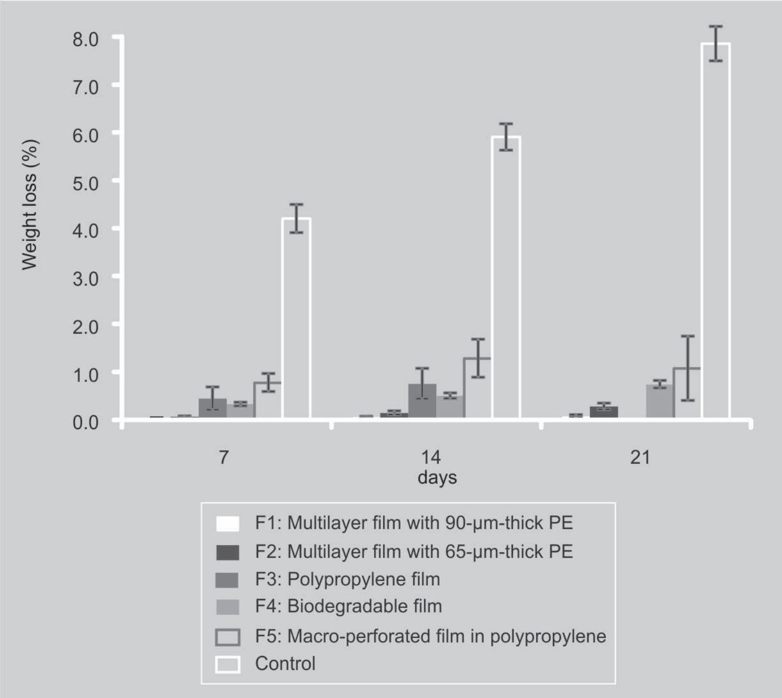

Figure 3.
Evolution of weight loss (%) of apricots cv. Tom Cot® stored in modified atmosphere packaging at + 1 °C. Multilayer film was obtained from coextrusion of polyethylene terephthalate (PET), ethylene vinyl alcohol (EVOH) and polyethylene (PE).

atmosphere until the end of storage. After 14 days, values of 4.6 kPa CO_2 and 18.5 kPa O_2 were measured inside the packages, but these values were not similar to previously reported data [11]. Fungi, most likely *Monilia* sp., developed on fruit wrapped with the F3 treatment; therefore, it was not possible to store apricots for up to 21 days.

The biodegradable film (F4 treatment) was the only treatment that was able to reach and maintain the equilibrium state; the amount of O_2 entering the package and the amount of CO_2 permeating out of the package were equal to the amount of O_2 consumed and the amount of CO_2 evolved by the packaged fruit, respectively [26]. This condition was achieved at 14 days of storage with 10.1 kPa CO_2 and 10.7 kPa O_2 and agrees with the range of values reported by Pretel *et al.* [14].

The weight loss parameter is particularly useful for evaluating the success of storage. Generally, the weight loss of the apricot fruit increased over time, but its rate was dependent on the treatment (*figure 3*). According to the literature, the modified atmosphere packaging storage conditions decrease the weight loss that occurs in unwrapped fruits [12]. In fact, all treatments maintained values below 2% throughout the cold storage period.

The reduction in weight loss is related to the water vapour barrier of the packaging material, which is completely independent of its gas permeability properties [27]. This may explain why the use of polypropylene film (F3 treatment) also reduced the weight loss but did not affect the attainment of optimal values for the headspace gas composition (*figure 2*). As reported by Martinez-Romero *et al.* [28] and Perez-Pastor *et al.* [29], the water vapour barrier of the packaging materials affected apricot weight loss during storage. In fact, the F1 and F2 treatments maintained the lowest weight loss values during the entire storage time because of the high water vapour barrier effect of multilayer films [23].

Losses of approximately 5% to 8% of the fruit's water content can cause visual shrivelling and limit the marketability of stone fruit [30]. In our study, losses that occurred only in the control treatment affected the cosmetic appearance of the fruit as early as in the first week of storage.

Among all of the quality parameters (*table II*), the fruit flesh firmness was the most affected by the storage process in modified atmosphere packaging. Firmness decreased in control apricots from an initial value of 2.4 $kg\cdot cm^{-2}$ to 0.7 $kg\cdot cm^{-2}$ after 21 days of storage. This trend was also observed for the other treatments, but the fruits stored in modified atmosphere packaging exhibited a slower decrease.

After 21 days, the fruit flesh firmness values of apricots in modified atmosphere packaging were similar to those of control fruits. However, the highest values (1.3 $kg\cdot cm^{-2}$) were observed for fruits stored with multilayer films (F1 and F2), which maintained the highest state of hydration (*figure 3*) and the highest CO_2 concentrations (*figure 2*). In fact, softening during prolonged storage may be related to β-galactosidase and polygalacturonase (PG) activity, which has long been associated with fruit softening, but with varying amounts and activity across species [31]. High CO_2 and

Table II.
Evolution of qualitative characteristics of apricot fruit cv. Tom Cot® stored in modified atmosphere packaging at + 1 °C for 7 d, 14 d and 21 d. Value is the mean ± standard deviation.

a) Fruit flesh firmness (FFF) ($kg \cdot cm^{-2}$). At harvest, FFF = (2.4 ± 0.3) $kg \cdot cm^{-2}$

Treatment	7 d	14 d	21 d
F1: Multilayer film with 90-µm-thick PE	1.9 ± 0.6 bc	1.9 ± 0.8 a	1.3 ± 0.3 a
F2: Multilayer film with 65-µm-thick PE	1.5 ± 0.4 c	1.5 ± 0.6 bc	1.3 ± 0.2 a
F3: Polypropylene film	0.9 ± 0.2 d	1.3 ± 0.7 c	–
F4: Biodegradable film	2.4 ± 0.7 a	1.8 ± 0.7 b	1.1 ± 0.2 b
F5: Macro-perforated film in polypropylene	2.1 ± 0.9 ab	1.5 ± 0.4 bc	0.9 ± 0.3 bc
Control	2.0 ± 0.8 ab	1.3 ± 0.3 c	0.7 ± 0.2 c

b) Total soluble solids content (TSS) (°Brix). At harvest, TSS = (10.1 ± 1.4) °Brix

Treatment	7 d	14 d	21 d
F1: Multilayer film with 90-µm-thick PE	9.0 ± 1.2 bc	9.0 ± 1.3 c	10.3 ± 1.1 a
F2: Multilayer film with 65-µm-thick PE	10.0 ± 1.6 a	10.2 ± 1.5 b	10.3 ± 0.9 a
F3: Polypropylene film	9.3 ± 1.5 b	11.9 ± 1.5 a	–
F4: Biodegradable film	8.5 ± 1.5 bc	9.2 ± 1.4 bc	10.1 ± 1.1 a
F5: Macro-perforated film in polypropylene	8.2 ± 1.1 c	8.9 ± 1.7 c	10.2 ± 0.8 a
Control	8.7 ± 1.1 bc	8.9 ± 2.1 c	9.2 ± 1.1 b

c) Titratable acidity ($mEq \cdot L^{-1}$). At harvest, titratable acidity = (17.3 ± 0.2) $mEq \cdot L^{-1}$

Treatment	7 d	14 d	21 d
F1: Multilayer film with 90-µm-thick PE	11.0 ± 1.3 ns	11.4 ± 0.2 a	10.3 ± 0.3 a
F2: Multilayer film with 65-µm-thick PE	9.9 ± 0.1 ns	10.5 ± 0.4 a	10.2 ± 0.4 a
F3: Polypropylene film	9.0 ± 0.1 ns	10.5 ± 0.7 a	–
F4: Biodegradable film	10.3 ± 1.7 ns	10.5 ± 0.2 a	10.4 ± 0.5 a
F5: Macro-perforated film in polypropylene	9.4 ± 0.2 ns	7.5 ± 0.1 c	7.3 ± 0.2 c
Control	8.7 ± 0.3 ns	9.0 ± 0.1 b	8.5 ± 0.5 b

d) L^*. At harvest, L^* = 57.7 ± 1.8

Treatment	7 d	14 d	21 d
F1: Multilayer film with 90-µm-thick PE	54.0 ± 2.6 bc	54.0 ± 3.4 ab	55.9 ± 6.2 a
F2: Multilayer film with 65-µm-thick PE	52.7 ± 3.4 b	52.7 ± 3.8 abc	56.1 ± 3.2 a
F3: Polypropylene film	55.5 ± 2.9 c	55.8 ± 3.6 a	–
F4: Biodegradable film	52.9 ± 2.7 b	48.2 ± 6.4 d	54.4 ± 4.2 ab
F5: Macro-perforated film in polypropylene	52.2 ± 2.3 ab	50.9 ± 2.3 bcd	53.8 ± 6.5 ab
Control	50.4 ± 3.8 a	50.3 ± 2.0 cd	53.7 ± 4.8 ab

e) C^*. At harvest, C^* = 31.9 ± 1.5

Treatment	7 d	14 d	21 d
F1: Multilayer film with 90-µm-thick PE	29.9 ± 1.7 b	28.5 ± 1.9 b	36.1 ± 5.1 a
F2: Multilayer film with 65-µm-thick PE	30.3 ± 2.0 b	28.9 ± 2.4 b	34.8 ± 2.0 a
F3: Polypropylene film	35.6 ± 2.0 a	33.4 ± 3.4 a	–
F4: Biodegradable film	28.2 ± 1.7 c	25.0 ± 5.9 c	31.3 ± 4.0 b
F5: Macro-perforated film in polypropylene	27.4 ± 1.5 c	27.3 ± 1.6 bc	28.9 ± 6.1 bc
Control	26.8 ± 2.4 c	26.5 ± 1.3 bc	29.2 ± 4.5 bc

Table II. (Continued)

Evolution of qualitative characteristics of apricot fruit cv. Tom Cot® stored in modified atmosphere packaging at + 1 °C for 7 d, 14 d and 21 d. Value is the mean ± standard deviation.

f) *h**. At harvest, *h** = 70.8 ± 5.5

Treatment	7 d	14 d	21 d
F1: Multilayer film with 90-µm-thick PE	67.27 ± 5.2 b	69.93 ± 5.9 a	69.5 ± 3.6 a
F2: Multilayer film with 65-µm-thick PE	63.49 ± 3.3 c	64.48 ± 4.1 b	68.8 ± 4.8 a
F3: Polypropylene film	56.60 ± 3.1 d	57.86 ± 4.5 c	–
F4: Biodegradable film	68.92 ± 3.6 ab	69.24 ± 6.4 a	61.9 ± 7.2 b
F5: Macro-perforated film in polypropylene	68.26 ± 4.7 a	67.80 ± 4.1 ab	65.7 ± 8.5 ab
Control	68.67 ± 4.5 ab	69.92 ± 3.6 a	66.3 ± 6.3 ab

Multilayer film was obtained from coextrusion of polyethylene terephthalate (PET), ethylene vinyl alcohol (EVOH) and polyethylene (PE). Means with different letters are significantly different at a 0.05 level of significance using Tukey's test.

low O_2 in the storage environment could reduce the synthesis of enzymes, such as PG, which would result in a reduction of polymer breakdown in the cells of the apricot tissue [32].

The total soluble solids (TSS) content fluctuated during storage (*table II*). Apricots do not contain starch [33], so no conversion from starch to sugar occurs. The 10.1 °Brix measured at harvest decreased during the first two weeks of storage because of the increase in the respiration rate, which was demonstrated by the CO_2 values in the modified atmosphere packaging treatment. However, at the end of storage, the TSS values were similar to those at the harvest time for all wrapped fruits because of the increasing weight loss (water loss). Statistically significant differences were observed between the modified atmosphere packaging treatments and the control; in particular, the lowest values (9.2 °Brix) were measured for the unwrapped fruit because of the combined effect of respiration and weight loss.

The high titratable acidity (TA) levels observed at harvest (17.3 $mEq \cdot L^{-1}$) decreased throughout storage according to consumer preferences [3]. With up to 7 days of storage, no statistically significant differences were observed among the samples, and, as described in a previous study [14], no statistically significant differences were observed among the modified atmosphere packaging treatments (F1, F2 and F4) that yielded the highest CO_2 headspace gas composition (*figure 3*). Fruit wrapped with these films exhibited the highest TA values at both (14 and 21) days. Fruit exposed to air (F5 treatment and control) still exhibited significant TA differences because of the development of fungi (*Botrytis cinerea*) inside baskets wrapped with the perforated film (F5 treatment), which corresponded to the lowest TA values [(7.5 and 7.3) $mEq \cdot L^{-1}$] at (14 and 21) days, respectively.

For the chromatic characteristics of the stored fruits,there were significant differences in the L^*, C^* and h values among treatments (*table II*). The decreased L^* value reflects the darkening of the apricot varieties caused by carotenoid accumulation and indicates the occurrence of fruit ripening [34]. After 21 days, apricots wrapped with the perforated film (F5 treatment) and fruit maintained under the normal atmosphere (control) lost brightness more than those in the modified atmosphere packaging treatments, which exhibited lower L^* values of 53.8 and 53.7, respectively. No statistically significant differences were observed among fruit stored with the multilayer films (F1 and F2 treatments) because of the extremely similar headspace gas composition. These treatments displayed the highest L^* values because of the high CO_2 content in the headspace composition. After 21 days, the lowest C^* values were observed for the perforated film (F5 treatment) and for fruit maintained under the normal atmosphere. When compared with the harvest time (29.9), the observed decrease indicates an increase in the tonality of the fruit colour because of a decrease in chlorophyll and carotenoids. The multilayer films (F1 and F2 treatments) were not significantly different. At the end of storage, all treatments reduced the *b* values compared with the values observed at harvest. The loss of light reflection was reflected by a reduction in the *L** value (the photometric parameter proportional to the light reflected by the object) and was directly correlated with the humidity during storage [35]. In fact, the highest h values (69.5 and 68.8) were maintained by the multilayer films (F1 and F2 treatments, respectively), which corresponded to a high water vapour barrier.

4. Conclusion

Our study confirms the findings of a previous study that suggested that using modified atmosphere packaging is an effective approach to maintain the quality of apricots during cold storage (+1 ± 0.5) °C [14]. All films used were able to modify the initial headspace gas composition; the two multilayer films (F1 and F2 treatments) and the biodegradable film (F4 treatment) changed the internal atmosphere of packages containing apricots for up to 21 days of storage. Gas film permeability greatly influenced the composition of the internal atmosphere. The highest CO_2 values were measured throughout the entire storage time in apricots wrapped with the multilayer films (F1 and F2 treatments), which corresponded to the lowest values of gas permeability, as observed in a recent study on other stone fruits [15]. Control of relative humidity (RH) in packages is a critical aspect for modified atmosphere packaging storage, and excessively high RH caused by the impermeability of the film's water vapour barrier may cause moisture condensation, microbial growth and decay [36], as observed in our study with polypropylene film (F3 treatment).

Considering the fruit quality parameters, the multilayer films represent the best packaging materials to store apricots in modified atmosphere packaging for limiting weight loss, maintaining the pulp firmness and apricots with low acidity. However, the gas concentration at equilibrium is another important aspect that must be considered to manage modified atmosphere packaging, as reported previously [37]. The concentration inside the packages was at equilibrium when the gas quantity (CO_2 and O_2) exchanged through the fruit skin was the same as that exchanged through the film wrapping. An equilibrium was reached when the gas concentration inside the package stabilised, and this condition was observed only for the biodegradable film (F4 treatment); it was maintained until the end of storage. In conclusion, our work confirms the high performance of multilayer films as traditional materials and identifies biodegradable film as a new flexible packaging material for storing apricots in modified atmosphere packaging. As suggested by Weber *et al.*, to improve the applications of bio-based packaging, biodegradable films could be used to improve the water vapour barrier [38]. Further investigations are necessary to evaluate the performance of these films under different modified atmosphere packaging storage conditions.

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Efectos de los innovadores materiales de embalaje en la conservación del albaricoque (cv. Tom Cot®).

Resumen – **Introducción**. La innovación en el control de la alterabilidad/frescor representa un tema esencial en el sector de los frutos del futuro, no sólo para los sistemas comerciales y de distribución, sino también para su producción. Las películas de plástico con atmósferas modificadas representan una tecnología poscosecha que puede emplearse para almacenar los frutos de hueso, tales como los albaricoques, los cuales tienen una duración de vida corta cuando se mantienen en una atmósfera normal en condiciones refrigeradas. El objetivo de nuestro trabajo fue la evaluación del efecto de varios materiales de embalaje en la calidad poscosecha de albaricoques cv. Tom Cot® almacenados durante 21 días, acentuando las características cualitativas más importantes. **Material y métodos**. Se empleó la tecnología de la atmósfera modificada adaptada a diferentes materiales de embalaje para el almacenamiento de albaricoques cv. Tom Cot® a (+1 ± 0.5) °C y 90–95% de higrometría. Se desarrollaron diferentes condiciones de embalaje en atmósfera modificada (EAM), dada la interacción entre la respiración del fruto y las diversas barreras de oxígeno y de dióxido de carbono de las películas. Se evaluaron los efectos de los EAM en la calidad poscosecha de los frutos, valorando la composición del gas del espacio libre en el embalaje, la pérdida de peso, la firmeza del fruto, el contenido de sólidos solubles totales, la acidez valorable y el color de la piel. **Resultados y discusión**. Se observaron cambios de la composición de gas en el espacio libre de los embalajes en todas las películas utilizadas, pero sólo las películas multicapas y la película biodegradable mantuvieron las condiciones EAM hasta el final del periodo de almacenamiento. Los frutos envueltos perdieron menos peso que los frutos mantenidos en condiciones normales; particularmente, las películas multicapas permitieron obtener los valores de firmeza del fruto más elevados tras 21 días. La película biodegradable fue competente para mantener el equilibrio CO_2/O_2 en el interior de las cajas, equilibrando la respiración del fruto y la permeabilidad de la película. Las materias plásticas tradicionales, tales como las películas multicapas, y las películas más duraderas, tales como la película biodegradable empleada en nuestro estudio, pueden utilizarse exitosamente para conservar los albaricoques cv. Tom Cot® durante hasta 21 días en condiciones pasivas de almacenaje en atmósfera modificada.

Italia / *Prunus armeniaca* / frutas / aptitude para la conservación / film (empaque) / almacenamiento atmósfera controlada / calidad