PAPER

QUALITY INDICATORS FOR MODIFIED ATMOSPHERE PACKAGING (MAP) STORAGE OF HIGH-QUALITY EUROPEAN PLUM (*PRUNUS DOMESTICA* L.) CULTIVARS

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ABSTRACT

The use of quality indicators is crucial in selling plums in more distant markets and the evaluation of freshness through multiple index is fundamental to evaluate the goodness of the storage technique. In this study we evaluated the quality of two european plums cultivars ('Ramasin' and 'Ariddo di Core' with purple and yellow flesh colour respectively) after modified atmosphere packaging (MAP) storage, through the selection of the most appropriate indicators. The headspace gas composition, the flesh fruit firmness (FFF), the soluble solid content (SSC), the titratable acidity (TA), the colour and the chlorophyll content of plums wrapped with 5 different films (F1, F2, F3, F4 and F5) were evaluated for up 21 days of storage (at 1±1°C and 90-95% relative humidity). For both cultivars, the multilayered films (F1 and F2, 90 and 65 μm respectively) offered better effectiveness over other films. The total chlorophyll concentration, showing a good correlation with the colorimetric parameters of luminance (L*) and chroma (respectively R^2=0.92 and R^2= 0.96) confirmed, in the case of the Ariddo di Core cultivar, the results obtained by monitoring other parameters thus highlighting the usefulness of integrating multiple indexes in evaluating the performance of the storage methods used.

Keywords: Plum, film, quality index, chlorophyll, passive atmosphere

1. INTRODUCTION

Thanks to its adaptive behaviour in different climatic conditions, plums represent one of the most versatile of fruit trees species and its production is considered valuable for the future development of fruit trees sector (BLAZEK, 2007; SOTTILE *et al*., 2010a). In recent years the recovery and development of high quality local germplasm cultivars, such as the Ramasin in Piedmont and Ariddo di Core in Sicily, have evidenced a high level of diversity along the Italian production of the European plum (*Prunus domestica* L.). These cultivars have been important for local market since years; more recently they are also being coveted by wider markets for the high nutraceutical characteristics of fruits (SOTTILE *et al*., 2010b). The wide ripening period for such cultivars, combined with the different areas of cultivation, support an extension to the commercial calendar and represent a good opportunity for expanding the market for these fruits. The availability of numerous varieties, together with quality and price indicate the efficiency of the supply chain and distribution system which is today one of the most important sales channels in the area of horticultural fresh products (DEAN, 2011). The post-harvest management of these fruits appears problematic because plums evidence a cultivar-dependent high perishability, and require specific cares in terms of handling along all the supply chain. If not combined with other storage techniques, low refrigeration temperatures are not sufficient to maintain fruit quality up to the consumer; in fact, prolonged exposure to low temperatures would be responsible for enzymatic browning of the internal tissues and of the formation of skin damages (TAYLOR *et al*., 1993; ABDI *et al*., 1997). Among the different storage techniques such the use of absorbers (SHARMA *et al*., 2012) or antagonists of ethylene (SINGH and SINGH 2012), the modified and the controlled atmospheres (ELZAYAT and MOLINE, 1995; PRANGE and DELONG 2006; GIUGGIOLI *et al*., 2008; GIRGENTI *et al*., 2010; DIAZ-MULA *et al*., 2011 a, DIAZ-MULA *et al*., 2011 b, SOTTILE *et al*., 2013) are well known to have positive effect to improve the shelf life of plums. Active MAP on Sanacore and Ariddo di Core plums was performed with wrapped bulk preserving the quality more than 40 days for local consumption (PEANO *et al*., 2010) and different MAP box liners were used to maintain the shelf life and the quality of 'Friar' plums (CANTÍN *et al*., 2008). A key issue to success is also represented by high uniformity of the fruits as regards quality parameters (CRISOSTO *et al*., 2004). For this reason the selection and the monitoring of quality indicators is important not only for defining the time for harvesting but also for the maintainance of the commercial value of the product. There are several studies on the evolution of quality parameters during plum post-harvesting fruit management (USENIK *et al*., 2008; PÉREZ-MARÍN *et al*., 2010; SOTTILE *et al*., 2013;) but the identification of indicators useful to monitor quality along the distribution is still difficult. The pulp firmness and its relative evolution during storage is closely cultivar-dependent and specifically related to the stage of maturity at harvest time (SHARMA *et al*., 2012); anyway, if not integrated with other quality indicators, this parameter would be impractical for the fresh fruit market due to the absence of reference classes especially for European plums (VALERO *et al*., 2007; USENIK *et al*., 2008). In case of deeply pigmented cultivars, due to an usual early change of the skin colour, the pulp firmness is usually adopted as a ripening indicator (CRISOSTO and Kader 2000; SOTTILE *et al*., 2010 a). Generally, for stone fruits, the skin colour is one of the most important harvesting markers; the quantitative and qualitative development of the pigments in the skin is able to characterise the epidermis (chlorophyll, anthocyanins and carotenoids); the development of these pigments is closely related to the biological and physiological stress during the storage of the fruits (MERZLYAK *et al*., 1997; ABBOTT 1999). According to previous studies (SHARMA *et al*., 2012; VALERO *et al*., 2013) in some case the skin colour of purple-flesh plums is not a parameter useful to assess the effectiveness of differing

storage treatments. All these aspects are very important in affecting the aesthetic appearance of the product (ABBOTT 1999), while they have several limits and they are not always positively correlated to a correct stage of fruit ripeness (USENIK *et al*., 2008). It has been reported that a total soluble solids content (SSC) ranging from 14 to 16% (WESTWOOD 1978) or from 10 to 15% (DIAZ-MULA *et al*., 2009) determines fruit ready for consumption. However, the aromatic profile of plums, as of most stone fruit species, is even more affected by the total titratable acidity (TA) value than to the sugar content (CRISOSTO *et al*., 2004; CRISOSTO *et al*., 2007). Many studies (ZIOSI *et al*., 2008; INFANTE *et al*., 2011) have revealed a close correlation between chlorophyll content within the pulp tissues of the stone fruit and the ripening degree of the fruit; this evidence demonstrates that visible UV spectroscopy is a non-destructive technique which could be considered useful for monitoring and characterising the different stages of fruit ripening (ZUDE *et al*., 2003; CECCARELLI *et al*., 2008). It is therefore evident that the evaluation of the effectiveness of any post-harvest treatment should consider the uniformity of the fruit by including multiple quality indices; this aspect should be more valuable for those cultivars that are often considered minor for the lower diffusion but with a high commercial capacities if new post-harvesting techniques, such as modified atmosphere packaging (MAP), are developed.
On the basis of these considerations, the aim of this work was to evaluate the influence of the different packaging films used for MAP storage up to 21 days at 1 ±0.5°C of two European plum cultivars characterized by high tasting excellence and differing pigmentation (yellow and purple) also in order to assess the most important quality indices for fresh consumption.

2. MATERIALS AND METHODS

2.1. Fruit samples

Two European plum cultivars (*Prunus domestica* L.) were used, both belonging to local Italian germplasm and with different pigmentations: the cv. 'Ramasin' with a purple-coloured flesh is from the Piedmont territory and was harvested in mid-July; the cv. 'Ariddo di Core' is a yellow-coloured flesh variety from Sicily and is harvested in August. Both cultivars are characterised by fruits of small size and limited shelf life but with a high tasting quality well recognized by the local consumers. Fruits were picked by hand, and selected based on size uniformity and absence of damage. After a refrigeration (2 hours) they were placed in polyethylene terephthalate (PET) trays and transported within 24 hours to the fruit and vegetable warehouse (Agrifrutta Soc. Coop. S.R.L. - Piedmont, Italy) for storage-testing.

2.2. Packaging and storage conditions

The fruit samples were unwashed previously to be packaged. For both cultivars the sampling unit considered was the flowpack. The PET 0.250 kg trays (L14 x w9.5 x h5) were heat sealed with different films using a Taurus 700 model horizontal machine (Delphin, Italy). The materials used for the different packages were:

F1: multilayer produced by co-extrusion of PET, EVOH and PE of 90μm, (Corapack, Italy);
F2: multilayer produced by co-extrusion of PET, EVOH and PE of 65 μm, (Corapack, Italy);
F3: polypropylene (PP) film, 25μm, (Trepack, Italy);

F4: low density monolayer polyethylene (PE) film, 25 μm, (Trepack, Italy);
F5: non commercial biodegradable film, 25 μm, (Novamont, Italy);

For each package, the control sample (Control) is represented by fruits preserved using a polypropylene (PP) macroperforated (6 mm diameter holes) film of 25 μm (Trepack, Italy). The O_2 and CO_2 transmission rate properties of the films were measured at 23°C and 50% of relative humidity in accordance with ASTM F 2622-08 and ASTM F 2476-05 standards (Table 1). With the exception of the biodegradable film (F5) whose water permeability value was supplied directly by the manufacturer (147cm^3 m^{-2} 24h), tested films resulted within the high water barrier film classification (VAN TUIL, 2000). All fruits were packed under normal atmospheric conditions (0.2 CO_2 kPa /21.2 O_2 kPa). This was performed in order to create passive modified atmosphere packaging (MAP) during storage conditions through to the synergistic action of the fruit respiratory metabolism and the selectivity of the film to the gases. Due the macro hole (6-mm-diameter) the PP film (control) has no changed the atmosphere inside the packages along all the storage time. The fruits were stored for all the period under constant refrigeration conditions based on 1±0.5°C with a relative humidity (RH) level of 90-95% and in the dark. Qualitative evaluations were performed at the picking time (0) and after 7, 14 and 21 days of storage.

Table 1: Characteristics of film used for MAP storage of plum fruits.

Film gas transmission rate at 23°C and 50% UR cm^3/(m^2 24h bar)		
Film	**O_2 (ASTM F2622-08)**	**CO_2 (ASTM F2476-05)**
F1	1572	6111
F2	1572	6111
F3	1456	4616
F4	10990	55360
F5	2276	44494

2.3. Headspace Composition and Qualitative Parameters

Sampling of the gases (O_2 and CO_2) within the headspace of the packaging was performed with a Check Point II portable gas analyser (PBI Dansensor, Italy). Three random trays were used for each measurement for a total of 0.750 kg of fruit. In order to avoid any alteration to its internal atmosphere, the air sampled for analysis was fed back into the container using a porous septum (15 mm diameter PBI Dansensor, Italy) positioned on the surface of the film. Instrument calibration was performed after each measurement using a vacuum sample in normal atmosphere (ADAY and CANER, 2011). The value is recorded as kPa and it is the average of three measurements.
The weight of each container was measured using an electronic balance (SE622, WVR Science Education, USA) with an accuracy of 0.01 grams, at the harvest and at the end of each storage period. The relative weight loss was expressed as a percentage (%). The fruit flesh firmness (FFF) (kg/cm^2) was measured by a manual penetrometer (Facchini, Alfonsine, Italy) using a pipette tip with a 7.9-9 mm diameter in accordance with species standards. The skin of the fruit was not removed. Each value is the average of two measurements taken from opposite sides of each fruit. The data recorded is the average of

30 measurements (three random trays for a total of 0.750 kg of fruit). Soluble solids content (SSC) were determined in the juice (from three trays randomly chosen for each treatment) with a digital refractometer Atago PR-101 (Atago, Japan) at 20°C. Two readings (30 fruits) were taken on each fruit and averaged; results were expressed as °Brix.
The titratable acidity (TA) (meq/L) was measured with an automatic titrator (Titritino plus 484, Metrohm, Switzerland); 5 mL of pulp juice were used for each sample (shaken, centrifuged and filtered), diluted in 15 mL of distilled water which was neutralised with sodium hydroxide (NaOH) 0.1N. The value is the average of 3 measurements (three random plastic containers for a total of 0.750 kg of fruit).

2.4. Colour

In this study the colour evolution and total chlorophyll content were monitored only for the yellow-flesh cultivar cv. 'Ariddo di Core'. Colour was measured on the first 15 non-mouldy fruits from each tray (three trays were randomly chosen for each package). The mean of the 30 fruit measurements was used for data analysis. CIELAB or L*a*b* space was used to describe the color. This color space is device-independent and able to create consistent colors regardless of the device used to acquire the image. L* is the luminance or lightness component, which ranges from 0 to 100, while a* (green to red) and b* (blue to yellow) are two chromatic components, with values varying from –120 to +120 (YAM and PAPAKADIS, 2004). These values were used to calculate chroma, which indicates the intensity or color saturation, using the following equation:

$$C^* = [a^{*2} + b^{*2}]^{1/2} \quad (2)$$

hue angle was calculated as follows:

$$h° = \text{arctangent}[b^* / a^*] \quad (3)$$

where 0° = red-purple, 90° = yellow, 180° = bluish-green, and 270° = blue (MCGUIRE, 1992).

2.5. Chlorophyll

Chlorophyll monitoring was carried out using UV-Vis spectrophotometry, a non-destructive analytical, qualitative and quantitative technique that makes use of a spectrophotometer to allow molecule recognition and quantification as a function of spectrum absorption. The UV-Vis analyses were performed using a Varian Cary 500 double beam spectrophotometer equipped with a Varian DRA-2500 integrating sphere. The background noise was subtracted using the Spectralon® as a reference. The spectra were recorded in a range between 350 and 800 nm at a resolution of 3 nm. Each UV-Vis measurement was made in diffuse reflection (DR) mode positioning the equatorial part of the surface of each fruit (95mm^2 area) in line with the reflection sphere. For each sample the chlorophyll concentration was calculated by processing the spectra acquired from each fruit (average of two fruit / 60 fruits / acquisitions) as per the Kubelka Munk (1931) F(R) function. It was first necessary to establish a calibration equation by means of the direct extraction of chlorophyll from plums exhibiting different degrees of maturity as per the official extraction methodology (AOAC, 2006).

2.6. Statistical analysis

All statistics were performed using SPSS for Windows version 20.0. The data obtained were treated with one-way analysis of variance (ANOVA) and the means were separated using the Duncan test ($p \leq 0.05$). As the sample sizes were identical, it was possible to perform a parametric test for the percentages.

3. RESULTS AND DISCUSSIONS

3.1. Headspace composition and qualitative parameters

Changes of O_2 and CO_2 (kPa) gases within the package headspaces are shown in Figs. 1 and 2 respectively for cv. 'Ramasin' and cv. 'Ariddo di Core'. For both cultivars each packaging film succeeded in changing the initial atmospheric conditions, equal to 0.2 kPa of CO_2 and 21.2 kPa of O_2 maintaining different MAP conditions up to the end of the storage period (21 days).

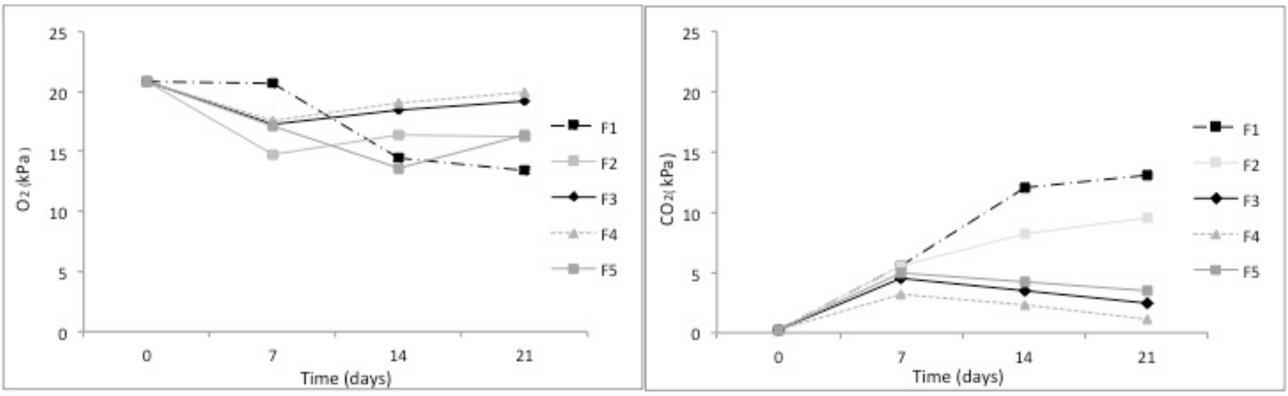

Figure 1: O_2 and CO_2 headspace gas composition of cv. 'Ramasin' plums stored in MAP at 1±0.5°C.

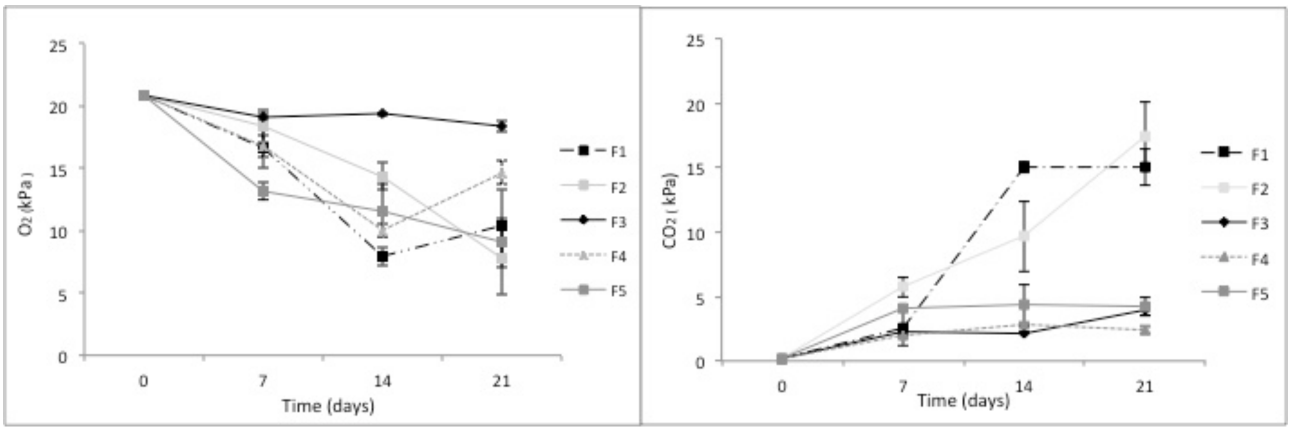

Figure 2: O_2 and CO_2 headspace gas composition of cv. 'Ariddo di Core' plums stored in MAP at 1±0.5°C.

In general a decreasing trend in O_2 content corresponds to an increase in the internal concentration of CO_2, product of the respiration of the plums; in this case, the CO_2 accumulation, at a constant temperature (1±0.5°C), is determined by the interaction of two factors: the permeability of the film and the storage period (EXAMA *et al*., 1993; VAROQUAUX *et al*., 2002). During the first 7 days O_2 and CO_2 contents did not differ significantly in both varieties. As the storage goes on, the values increases their differences evidencing the active performance of the different packaging films used. According to what reported in previous MAP studies on stone fruits (DIAZ-MULA *et al*., 2011 a, GIRGENTI *et al.,* 2014) the multilayer films (F1 and F2) are able to maintain higher concentrations of CO_2 within the flow pack when compared with other films (F3, F4, F5) due to higher gas barrier properties (Table 1).
This condition is maintained by both the cultivars for all the storage time. In particular, after 21 days of storage, CO_2 ranged between 9.5 and 13.1 kPa for cv. 'Ramasin' and between 15.0 kPa and 17.4 kPa of CO_2 for cv. 'Ariddo di Core'. With the 'Ramasin' cultivar, the highest value is registered with the F1 film, while for the cv. 'Ariddo di Core' with the F2 film. All other films, from the 7^{th} day of storage evidenced CO_2 values lower than 5 kPa. For both cultivars the lowest values were obtained with the F4 film (respectively 1.2 kPa for the cv. 'Ramasin' and 2.4 kPa for the cv. 'Ariddo di Core'). Throughout the storage period, the cv. 'Ariddo di Core', under all MAP conditions, presented higher values of CO_2 than the cv. 'Ramasin', suggesting a greater respiratory metabolism for the fruit of this cultivar. For the cv. 'Ramasin', the equilibrium point (13.4 kPa O_2 and 13.1 kPa CO_2) was only reached at the end of the storage period (21 days) with the F1 film, while in the case of the cv. 'Ariddo di Core' it is reached between the 14^{th} and 21^{st} day with both of the multilayer films (F1 and F2) with values ranging between 10 and 15kPa; this condition is however immediately lost. The weight losses observed (data not shown) increase with the storage time, but the rate for both cultivars is a function of the specific film employed. The control showed the greatest weight loss (3 % of the fresh weight after 21 days) confirming what was observed in previous MAP studies for stone fruits (SOTTILE *et al*., 2013; GIRGENTI *et al.,* 2014). All MAP packages ensure controlled weight loss within a similar range of values (0.5-0.7% for cv. 'Ramasin' and 0.6-0.9 % for 'Ariddo di Core' after 21 days of storage). Based on these results, it is not possible to use the weight loss as quality parameter to identify the MAP film with the best performances.
The cv. 'Ramasin' (Table 2) and cv. 'Ariddo di Core' (Table 3) present very different FFF values at harvest (1.1 kg/cm^2 and 3.5 kg/cm^2 respectively). However both cultivars exhibit a similar evolution for this parameter. In fact, the FFF values decreased with time, reaching their lowest values after 21 days of storage. This result is associated with a decrease of pectin polymerisation within the cell tissues and although this trend is common to all packages, fruit stored under normal atmospheric conditions (control) showed a stronger decreasing trend and evidenced values significantly lower at the end of the storage period respect to MAP storage (0.5 kg/cm^2 for cv. 'Ramasin' and 1.1kg/cm^2 for 'Ariddo di Core').
As reported in previous studies (SOTTILE *et al*., 2013) plums stored under MAP conditions with the highest levels of CO_2 use to evidence higher pulp firmness; for both cultivars the multilayer films (F1 and F2), ensuring higher values of CO_2 (Figs. 1 and 2), are able to better control pulp firmness decay as compared to other films.
In particular, for cv. 'Ramasin', the F1 film is significantly different compared to the F2 film, while in the case of the cv. 'Ariddo di Core', these two films do not exhibit significant differences in terms of performance.

Table 2: Evolution of qualitative characteristics of plums cv. 'Ramasin' stored in MAP at 1±0.5°C.

		Time (days)		
	Film	**7**	**14**	**21**
		Harvest 1.10±0.2[1]		
FFF (kg/cm^2)	F1	0.86±0.2^a	0.85±0.1^a	0.80±0.2^a
	F2	0.89±0.1^a	0.84±0.1^a	0.80±0.1^b
	F3	0.77±0.1^a	0.70±0.1^a	0.78±0.2^b
	F4	0.78±0.1^b	0.70±0.1^a	0.71±0.1^b
	F5	0.76±0.1^b	0.72±0.1^a	0.73±0.1^b
	Control	0.62±0.1^c	0.53±0.1^b	0.49±0.2^c
		Harvest 16.0±0.7		
SSC (°Brix)	F1	17.0±0.3$^{n.s}$	17.5±0.3^d	17.9±0.5^d
	F2	17.0±0.4$^{n.s}$	17.7±0.3^d	17.9±0.7^d
	F3	16.9±0.6$^{n.s}$	18.2±0.8^{bc}	18.6±0.5^{bc}
	F4	17.1±0.8$^{n.s}$	18.0±0.5^c	18.5±0.6^c
	F5	17.1±0.3$^{n.s}$	18.3±0.6^b	18.8±0.3^b
	Control	17.0±0.6$^{n.s}$	18.8±0.3^a	20.1±0.5^a
		Harvest 5.1±0.0		
TA (meq/L)	F1	4.9±0.0$^{n.s}$	4.8±0.2^a	4.5±0.0^a
	F2	4.9±0.2$^{n.s}$	4.8±0.1^a	4.5±0.1^a
	F3	5.1±0.1$^{n.s}$	4.6±0.3^a	4.5±0.0^{ab}
	F4	5.0±0.1$^{n.s}$	4.6±0.1^a	4.4±0.0^{ab}
	F5	5.0±0.1$^{n.s}$	4.5±0.1^a	4.4±0.0^b
	Control	5.0±0.1$^{n.s}$	4.2±0.2^b	3.7±0.1^c

Results were expressed as means ± standard deviation.
Values in the column followed by different letters are significantly ($P<0.05$) different according to Duncan's test.

At harvest, the two cultivars present different SSC (16.0° Brix and 18.5° Brix respectively for cv. 'Ramasin' and cv. 'Ariddo di Core'). After the first 7 days of storage, in spite of the low refrigeration temperatures (1 ±0.5°C), all packages presented an increase in the soluble solids content values in accordance with the observations of GUERRA and CASQUERO (2008), with the Green Gage variety and SOTTILE *et al.*, (2013) yellow-fleshcultivars; this trend is evident with continued storage. The increase is related to the concentration of sugars resulting from weight loss of the fruit (loss of water) and also due to the increasing extractability (sucrose inversion) during the increasing of the ripening degree. For both cultivars, over the whole storage period, the control presented a higher soluble solid content compared to the MAP packaged ones thus confirming the CO_2 effect during storage and its ability to delay the ripening processes in accordance with DÍAZ-MULA *et al*. (2009).

The F1 and F2 films showed statistically significant differences compared to the other MAP films (F3, F4 and F5) after 14 days of storage in the case of the cv. 'Ramasin' (Table 2) and after only 7 days of storage for the cv. 'Ariddo di Core' (Table 3) evidencing a better control of the soluble solids content dinamics and maintaining these values close to those measured at harvest.

Table 3: Evolution of qualitative characteristics of plums cv. 'Ariddo di Core' stored in MAP at 1±0.5°C.

		Time (days)		
	Film	**7**	**14**	**21**
		Harvest 3.55±0.11		
FFF (kg/cm^2)	**F1**	3.25±0.1 [a]	3.25±0.3 [a]	2.39±0.1 [a]
	F2	3.25±0.1 [a]	3.04±0.1 [a]	2.49±0.2 [a]
	F3	2.85±0.2 [b]	2.50±0.1 [b]	1.32±0.2 [c]
	F4	2.79±0.1 [b]	2.47±0.1 [b]	1.35±0.2 [c]
	F5	2.87±0.1 [b]	2.50±0.1 [b]	1.53±0.2 [b]
	Control	2.53±0.1 [c]	2.24±0.4 [c]	1.04±0.1 [d]
		Harvest 18.5±0.1		
SSC (°Brix)	**F1**	18.6±0.1 [bc]	18.7±0.1 [c]	19.1±0.2 [c]
	F2	18.6±0.1 [bc]	18.7±0.1 [c]	19.0±0.1 [c]
	F3	18.7±0.1 [b]	19.1±0.0 [b]	19.5±0.1 [b]
	F4	18.7±0.1 [b]	19.0±0.1 [b]	19.5±0.1 [b]
	F5	18.7±0.1 [b]	19.0±0.1 [b]	19.5±0.1 [b]
	Control	18.9±0.1 [a]	19.6±0.1 [a]	20.0±0.1 [a]
		Harvest 8.6±0.7		
TA (meq/L)	**F1**	5.0±0.1 [n.s]	4.3±0.0 [n.s]	4.1±0.1 [a]
	F2	5.0±0.1 [n.s]	4.4±0.1 [n.s]	4.1±0.0 [a]
	F3	4.5±0.0 [n.s]	4.3±0.0 [n.s]	3.6±0.0 [b]
	F4	4.5±0.1 [n.s]	4.3±0.0 [n.s]	3.5±0.0 [b]
	F5	4.5±0.0 [n.s]	4.3±0.1 [n.s]	3.5±0.0 [b]
	Control	4.5±0.0 [n.s]	4.1±0.1 [n.s]	3.9±0.0 [c]

Results were expressed as means ± standard deviation.
Values in the column followed by different letters are significantly (P<0.05) different according to Duncan's test.

Over the entire storage period, compared to the values measured at harvest (5.1 meq/L for cv. 'Ramasin' and 10.2 meq/L for cv. 'Ariddo di Core'), the TA diminished for all packages for both cultivars; both for Ramasin and Ariddo di Core cvs., MAP determined higher TA values compared to the control. The maturity index obtained from the SSC/TA ratio (data not shown) indicates a progressively increase during the whole storage period for both cultivars; for all MAP packages this value is lower respect to the control, thus confirming the observations reported from previous studies (DÍAZ-MULA *et al*., 2009).
The colour variables a* and b* are not independent and their difficult perception to the human eye force to their correlation in order to calculate Chroma (C) and Hue angle parameters (ALCOBENDAS *et al*., 2012). Table 4 reports the colour components L*, Chroma and Hue angle as measured for the yellow flesh fruit cv. 'Ariddo di Core'. Just after 7 days of storage each film packaging influenced a change in skin colour thus indicating the presence of a maturation process even at low storage temperatures (1±0.5°C).

3.2. Colour and chlorophyll monitoring

The luminance values (L*) decrease compared to those measured at harvest (46.9) thus indicating a darkening of the tissues as a result of the ripening (Table 4). Each of the MAP packages presented no statistically significant differences compared to control as the fruit maintained higher L* values. The multilayer films (F1 and F2), to which correspond higher concentrations of CO_2 within the flow pack headspace (Fig. 2), are more differentiated than the other films presenting significantly higher values of L* over the entire storage period and reaching after 21 days values equal to 42.4. The chroma values follow in a similar way the decreasing trend of L* values. For each film the Hue angle values decreased at increasing storage time in accordance with findings reported by DÍAZ-MULA *et al*. (2011 a), but statistically significant lower values (redder fruit) were observed throughout the storage period in respect to control packed fruit.

Table 4: Colorimetric parameters of plums cv. 'Ariddo di Core' stored in MAP at 1±0.5°C.

Time (days)	Film	L*	Chroma	h angle
	Harvest	46.9±0.5^{a}	21.1±0.4^{a}	-1.31±0.01^{d}
7	F1	43.7±0.2^{b}	17.0±0.6^{bc}	-1.39±0.02^{c}
	F2	43.7±0.3^{b}	17.1±0.9^{bc}	1.39±0.02^{c}
	F3	43.6±0.2^{b}	16.9±0.6^{c}	-1.42±0.01^{b}
	F4	43.3±0.3^{c}	16.9±0.8^{b}	-1.40±0.01^{b}
	F5	43.4±0.3^{c}	16.9±0.9^{c}	-1.42±0.01^{b}
	Control	42.5±0.3^{d}	15.8±0.9^{d}	-1.48±0.03^{a}
	Harvest	46.9±0.5^{a}	21.1±0.4^{a}	-1,31±0.01^{c}
14	F1	43.5±0.2^{b}	16.3±0.5^{b}	-1.36±0.54^{bc}
	F2	43.6±0.3^{b}	16.3±0.6^{b}	-1.45±0.04^{ab}
	F3	42.4±0.2^{d}	15.6±0.7^{c}	-1.47±0.02^{a}
	F4	42.5±0.2^{cd}	15.7±0.4^{c}	-1.48±0.03^{a}
	F5	42.5±0.3^{c}	15.6±0.3^{c}	-1.48±0.01^{a}
	Control	41.6±0.4^{e}	13.2±0.7^{d}	1.53±0.00^{a}
	Harvest	46.9±0.5^{a}	21.1±0.4^{a}	-1.31±0.01^{c}
21	F1	42.4±0.3^{b}	15.6±0.8^{b}	-1.47±0.04^{b}
	F1	42.4±0.5^{b}	15,3±0.8^{b}	-1.47±0.02^{b}
	F1	41.6±0.2^{c}	14.3±0.8^{c}	-1.47±0.02^{b}
	F1	41.7±0.2^{c}	14,6±0.7^{c}	-1.48±0.02^{b}
	F1	41.6±0.4^{c}	14.6±0.6c	-1.48±0.02^{b}
	Control	39.5±0.3^{d}	12.6±0.8^{d}	-1.55±0.03^{a}

Results were expressed as means ± standard deviation.
Values in the column followed by different letters are significantly ($P<0.05$) different according to Duncan's test.

The skin changes from green to yellow color are closely correlated to the chlorophyll degradation process during ripening (ABDI *et al*., 1997; CRISOSTO *et al*., 2004) as shown in Fig. 3. The total pigment content, measured using UV-Vis spectrophotometry, decreases progressively throughout the storage period thus confirming evolution of the ripening processes even at low temperatures (ZUDE-SASSE *et al*., 2002; SOLOVCHENKO *et al*., 2005). For each quality control all MAP film tested evidenced to be able to manage the loss of total chlorophyll content maintaining higher values than the control. The high barrier capacity films (F1 and F2) were differentiated already within 7 days of storage thanks to the fruits have maintained the main quality values near to the time of harvest.

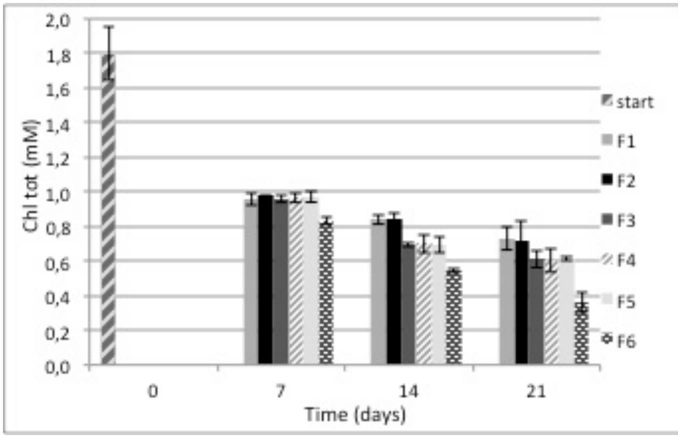

Figure 3: Chlorophyll total content (mM) in cv. 'Ariddo di Core' plums stored in MAP at 1±0.5°C.

The high CO_2 levels, corresponding to F1 and F2 films, (Fig. 2*)* would be responsible for the proper maintenance of the integrity and fluidity of cell membranes which are indispensable conditions for the stabilisation of the photosynthetic pigment content (PONGPRASERT *et al*., 2011). The total chlorophyll content showed a good correlation to the colour components L* (Fig. 4) and Chroma (Fig. 5) according to a linear regression index equal to R^2= 0.92 and R^2= 0.96, respectively. In particular, decreasing values in chlorophyll correspond to a loss of brightness and chromaticity (Table 4) associated with the concentration of carotenoids that are responsible for the change in colour from green to yellow (increasing value of a*) of the fruit skin.

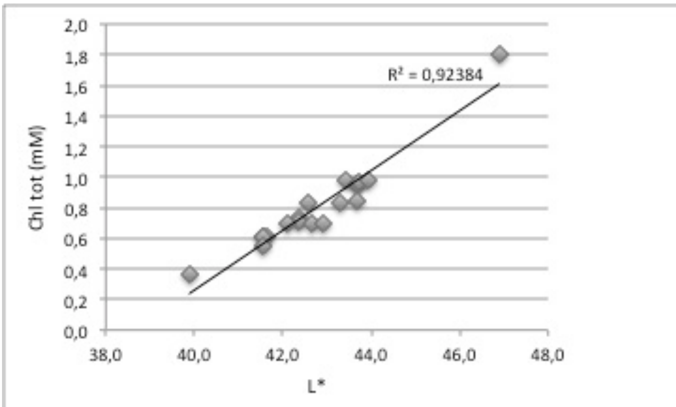

Figure 4: Linear regression of total chlorophyll content and the L* colour parameter in cv. 'Ariddo di Core' plums stored in MAP at 1±0.5°C.

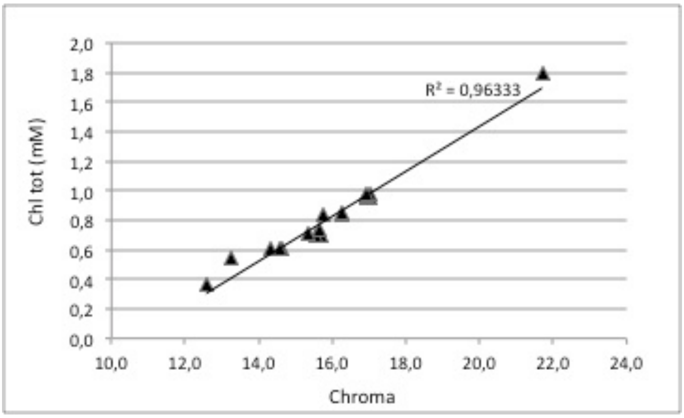

Figure 5: Linear regression of total chlorophyll content and the Chroma colour parameter in cv. 'Ariddo di Core' plums stored in MAP at 1±0.5°C.

4. CONCLUSIONS

Differents and multiples indexes of quality have been considered to evaluate the goodness of the MAP technique for the storage of 'Ramasin' and 'Ariddo di Core' plum cultivars. The headspace composition showed how high CO_2 increments associated with higher barrier capacity films (multilayer) are usually related to a higher fruit quality at the end of the storage period. Among the qualitative index considered, for both cultivars, the flesh fruit firmness allowed a better evaluation of the effectiveness of different packaging since the beginning of the storage test. The colour parameter (lightness and chromaticity), linked to the chlorophyll content of the plums, is well known to be particularly appreciated by the consumers and for this it can be suggested to further evaluation of the performance of the tested films for the management of a MAP storage protocol. Results of this research confirm the correlation that exists between colour and the pigments content in organic matrices and more generally within food systems (RAMAKRISHNAN and FRANCIS, 1973; FRANCIS, 1985; WATADA and ABBOTT, 1975; TAKAHATA *et al*., 1993; AMENY and WILSON, 1997; CHEN and TANG, 1998; ARIAS *et al*., 2000; BRON *et al*., 2005; CECCARELLI *et al*., 2008). According to McGuire (1992) the monitoring of the total total chlorophyll content is highly correlated with the colour parameters, then it is important to consider also that it derives from a non-destructive technique such as UV-Vis whose numerous advantages are even more interesting when they can be applied to cultivars of excellence and high perishability such as those considered within this study.

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