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Research Paper

Influence of different packaging materials in the raspberries quality supply chain

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ABSTRACT

The quality of fruits depend mostly, on packaging materials. We evaluated one commercial polypropylene macro-perforated film (6 mm holes) film (F1) and two non commercial biodegradable and compostable films (F2 and F3) with four baskets materials (polyethylene terephthalate, polylactic acid, cardboard and bagasse) to storage raspberries cv. Grandeaur® for up to 13 days (5 days at 1±1°C and 8 days at 20±1°C). The modified atmosphere packaging (MAP) and the quality of stored raspberries were evaluated monitoring respectively the headspace gas composition, the weight loss, the colour, the soluble solids content (SSC) and the titratable acidity (TA). The F2 and F3 film have modified the CO_2 and O_2 kPa in the packages, which depended on both the respiration of the berries and the permeability of the films. The effect of the storage and the packaging materials on the weight loss evolution wasn't significant while the most sensitive parameter was the colour. Generally MAP conditions have determined an increasing of the SSC and the decreasing of the TA values but baskets in PLA wrapped with the non commercial biodegradable and compostable film (package PLA–F3) globally has best maintained the SSC values near to the harvest time keeping the fruits quality more attractive (9.68 °Brix and 37.22 L after 13 days).

Key words: *Rubus ideaus*, packages, films, modified atmosphere, storage, temperatures.

INTRODUCTION

The storage and the marketability of the fresh raspberries represent a critical point along the supply chain due the highest respiration and traspiration rates of the fruits (Haffner et al., 2002). Post harvest loss in terms of value and consumer quality attributes can occur at any stage between harvest and consumption; more than 40% of raspberries losses has been estimated along all the supply chain of these high perishable berries and 28% of losses occurrs from wholesaler to the consumer (Pritts, 2003). Raspberries could be held no more than 7 days at 0°C and 90-95% RH, (Salunkhe and Desai, 1984), but technologies (controlled atmosphere storage, modified atmosphere packaging, equilibrium modified atmosphere packaging) able to manipulate the fresh produces respiration rate with the management of the gases concentration and the use of correct packaging permeability, have been largely studied (Callesen and Møller Holm, 1989; Agar and Streif, 1996; Kader, 2001; Haffner et al., 2002). Gaseous mixtures containing 10% O_2 and 15% CO_2 has been suggested as the best one to improve the shelf life of the fruits, to reduce the dacay and to maintain a more attractive color of the berries (Haffner et al., 2002). The management of packaging is necessary, especially in sectors where packaging is integral to handling and transportation and when the cool temperature are not guaranteed. Packaging technologies influence positively the shelf life of berries fruits but the materials used can widely negativelyinfluence the environment impact assessment in terms of global warming potential (GWP) and non-renewable energy (Girgenti et al., 2013). Among the different materials for fresh horticultural produce handling such as wood crates, corrugated shipping boxes, polymeric films pouches, bags, baskets, crates, trays, paper sheets, pouches, (Pascall, 2010), the polyethylene terephthalate (PET) is the most commonly used packaging material, world-wide, for marketing berries and vented clamshell containers are widely used in retail and wholesale packaging to protect fruits from damage. Since traditional packaging isone of the most relevant waste source and have environmental impacts that are not sustainable in the long term, to improve the shelf life of perishable commodities such as raspberries today the fresh food supply chain have to include in the packaging technology developments in the sustainability and in the environment. The recycling and the reduction of packaging materials, the waste disposal and the use of bio-packaging that use biopolymers from a renewable raw materials (polylactic acid, polyhidrxyalkanoates and thermoplastic starch (Weber et al., 2002) could be a promising alternative in the packaging sector. The substitution of the most commonly used packaging material such as the polyethylene terephthalate (PET), for marketing berries with PLA® baskets and Mater-Bi® film could be an interesting alternatives to the plastic materials derived from fossil fuel to reduce the environmental impacts (Girgenti et al., 2013). The headspace gas evolution inside different raspberries modified atmosphere packaging (MAP) was showed to be more influenced by the film characteristics rather than by the initial gas concentrations of packaging processing (Peano et al., 2013). The potential use of the new packaging materials based on renewable resources for the fresh fruits have to consider the main problem of the degree of thepermeability to gas (O_2 and CO_2) and to the water. One of the problems occurring for cardboard package is the reduction of its strength under high humidity storage conditions while starch cornfilms present relevant high water vapour permeability. Research on alternative materials to conventional one, suggested interesting innovation in the berries packaging sector but limited data are reported on the use of these materials to store highly perishable raspberry fruits under passive MAP along all the supply chain (Peano et al., 2013). The objective of this study was to evaluate the performance of different packaging materials from renewable source to store the raspberry fruits cultivar Grandeur®up to 13 days of storage under the cool storage temperatures of 1±1°C and the most common temperatures at European retail points of 20±1°C.

MATERIALS AND METHODS

Plant material

Red raspberry (*Rubus idaeus* L.) cv. Grandeur®fruits were obtained from a commercial orchard of the Agrifrutta Soc. Coop. SRL (Piedmont, Italy). The fruits were picked by hand in the middle of September at the red-ripe stage of maturity, were graded for uniformity of color and size and they were immediately transferred to the laboratory under cold conditions (5±1°C and 80-85% RH) for the different packaging procedures which started approximately 3 h after harvest.

Fruit packaging and post harvest storage conditions

The experimental storage units consisted in raspberries packages (samples) for the consumer (flowpack) of different materials (net weight 0.125 kg per tray) (Table 1). Polyethylene terephthalate (PET) (9×13.5×2.5 cm) (Trepack, Italy), polylactic acid (PLA) (9.5×14×2.5 cm) (Ilip, Italy); cardboard (9.5×12×4.8 cm) (NNZ, Derbyshire, UK) and bagasse (11×13×4.5cm) (RootsBiopack, Italy) baskets were wrapped with the three films. The films were: a commercial polypropylene macro-perforated film (6 mm holes) (Trepack, Italy) (F1) that is actually used in the retailer distribution; a non-commercial biodegradable and compostable film of 25 µm (Novamont, Italy) (F2); a non-commercial biodegradable and compostable filmof15 µm (Novamont, Italy). The oxygen (O_2TR) and carbon dioxide (CO_2TR) transmission rates of the non commercial films (798 and 2581 $cm^3/m^2/d/bar$ for F2 and 1316 and 5135 $cm^3/m^2/d/bar$ for F3) were measured at 23°C and 50% RH using a Multiperm Oxygen and Carbon Dioxide Analyser (Extra Solution s.r.l., Pisa, Italy) following respectively the ASTMF2622-08 and the ASTMF2476-05. All samples were sealed under ordinary atmospheric conditions (0.2 kPa CO_2 and 21.2 kPa O_2) using a flow pack equipment, a Taurus 700 (Delphin, Italy) electronic horizontal wrapping machine that includes a take-up reel with translational movement of the clamping jaws was used. The fruits were stored at 1±1°C in a cold room held at 90-95% RH for 5 days. After the cool storage, according to the internal procedures of the packing house, the fruits were held for 8 additional days in a room at 20±1°C to simulate the retailer conditions.

Analysis and sampling procedures

All analyses, with the exception of the headspace gas composition, were performed for each sample at five time points: at harvest (0); after 3 and 5 days at the constant temperature of 1±1°C; after 5 days from the change of the storage temperature at 10 days (20±1°C) and at the end of the storage period 13 days (5 days at low temperature + 8 days at high temperature). Three randomly selected baskets (0.375 kg of raspberry fruits) were used for each analysis.

Headspace gas composition

The headspace gas composition inside each package changed in the storage time due to the combined effect of

Table 1. Packages (samples) used in the experiment performed.

		Film		
		F1	F2*	F3**
		commercialpolypropylene macro-perforated film, 25 µm (6-mm holes) Trepack, Italy	non-commercial biodegradable and compostable film, 25 µm (Novamont, Italy)	non-commercial biodegradable and compostable film, 15 µm (Novamont, Italy)
		Packages		
Basket	Polyethylene terephthalate (PET) Trepack, Italy (9x13.5x2.5cm)	Control	-	-
	Paperboard NNZ, Derbyshire, UK (9.5x12x4.8cm)	-	PB-F2	PB-F3
	Polylactic acid (PLA) Ilip, Italy (9.5x14x2.5cm)	-	PLA-F2	PLA-F3
	Bagasse (RootsBiopack, Italy) (9.5x12x4.8cm)	-	BA-F2	BA-F3

*O_2 TR and CO_2 TR of 798 and 2581 $cm^3/m^2/d/bar$ at 23°C and 50% RH according to the ASTMF2622-08 and the ASTMF2476-05. **O_2TR and CO_2 TR of 1316 and 5135 $cm^3/m^2/d/bar$ at 23°C and 50% RH according to the ASTMF2622-08 and the ASTMF2476-05.

the respiration of the cv. Grandeur®, the films acting as a barrier to gases, and the temperature. Therefore, to measure the relative changes of the carbon dioxide and oxygen concentrations a CO_2 and O_2 analyser (Check Point II, PBI Dansensor, Italy) was used. The values were measured randomly over the period of the trial and were expressed as v/v kPa. To avoid modifications in the headspace gas composition due to gas sampling, the same free air volume was maintained in the packages across the trial period (thanks to a modification to the made by the supplier) because the analyser introduced the same quantity of air as it removed for the analyses. To prevent gas leakage during the measurement, an adhesive septum (Septum white 15 mm diameter, Dansensor, Italy) was placed on the surface of the package. The results are expressed as an average of three replicates.

Fruit quality assessment

The weight (water) loss of each raspberry tray was measured using an electronic balance (SE622, WVR, Science Education, USA) with an accuracy of 0.01 g. The weight of each tray was recorded at harvest and at the end of each storage period. Weight loss was expressed as the percent loss from the initial weight. The results are expressed as an average of three replicates. Soluble solids contents (SSC) were determined in the juice (three baskets were randomly chosen for each package) with a digital refractometer Atago PR-101 (Atago, Japan) at 20°C; results (average of two readings) were expressed as °Brix. The titratable acidity (TA) was determined by titration (Titritino 702, Metrohm, Switzerland) with 0.1 N NaOH up to pH 8.1, using 10 ml of diluted juice in distilled H_2O, and results were expressed as meq/L. Color was measured on the first 15 sound, non-mouldy fruits from each sample (three baskets were randomly chosen for each package). The mean of the 30 fruit measurements was used for data analysis. Color was measured on the side of a slightly flattened whole fruit using a tristimulus color analyser (Chroma Meter, Model CR-400, 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 Commission Internationale d l'Eclairage (CIE) Illuminant C. The CIELAB or L*a*b* space was used to describe the colour. 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 the colour saturation (chroma) as $C= [a^2 + b^2]^{1/2}$and the redness (hue angle) as h = arc tangent [b/a] (Hung, 1990; McGuire, 1992).

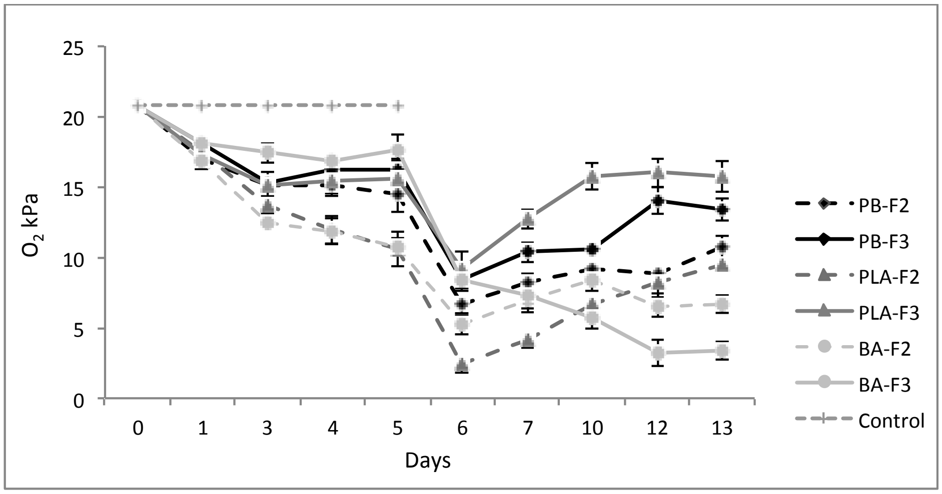

Figure1. O_2 (%) headspace composition in the raspberries samples under different packaging materials during the storage time.

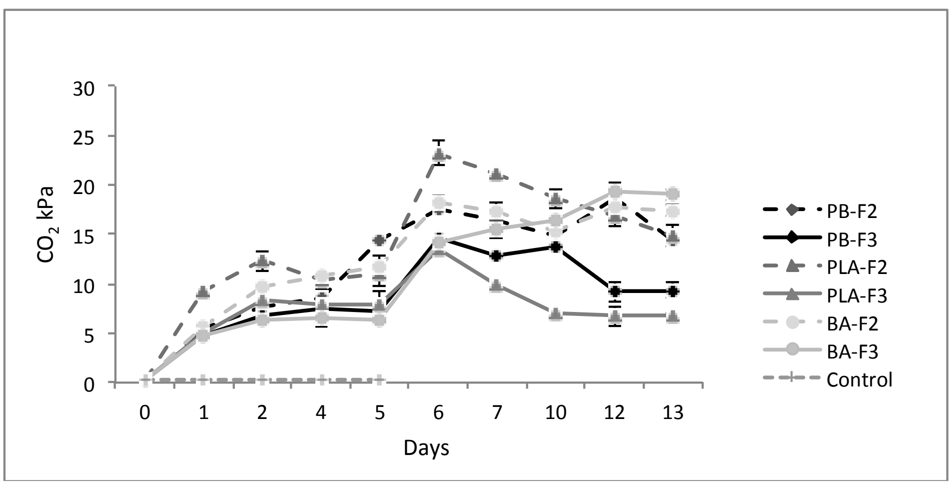

Figure 2. CO_2 (%) headspace composition in the raspberries samples under different packaging materials during the storage time.

Statistical analysis

All statistical analyses were performed using SPSS Statistics 20 statistical package software (SPSS Statistics 20, 2013, IBM, Italy) for Windows. The obtained data were treated using a two-way analysis of variance (ANOVA), and the means were separated using Tukey's test ($P \leq 0.05$).

RESULTS AND DISCUSSION

Headspace gas composition

Figures 1 and 2 show the changes in the O_2 and CO_2 headspace gas composition of raspberries packaged during the storage. The gas permeabilities of the F2 and F3 wrapping films,the respiration rate of the raspberry fruits and the change of the temperature altered the gas composition of all packages during all the storage time. The macro perfored film F1 (control) maintained air conditions (21 kPa O_2-0.02 kPa CO_2–balance N_2), due to no barrier effect, up to 5 days time after which raspberries have not been considered more marketable. Already after few hours from packaging at low temperature (1±1°C) a decrease in the O_2 headspace and an increase in the CO_2 headspace over time was observed. For all the storage time fruits packaged with the F2 film showed CO_2 values higher than fruits wrapped with the F3 due the highest barrier to gas and the major tickness of the film. Fruits packaged in the PLA baskets (PLA-F2) maintained CO_2 levels superior than raspberries stored in the paperboard and bagasse baskets (PB-F2 and BA-F2) probably due to the lower porosity of the baskets material. According to

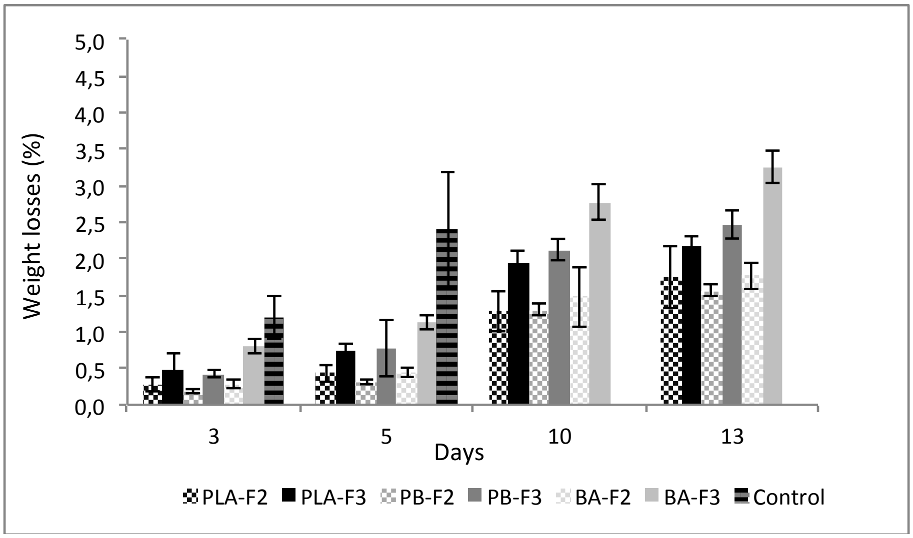

Figure 3. Weight losses (%) of raspberries by the storage time in different packaging materials.Each data point represents the mean of three replicate. Error bars represent the standard deviation of that mean.

findings of Seglina et al. (2010) the O_2 levels for raspberries wrapped with the F2 film were found higher in samples packaged with the paperboard material (PB-F2) because a portion of air was absorbed by the pores of the baskets.

With the increase of the temperature from 6 days to the end of the storage both the biodegradable films (F2 and F3) were able to control the oxygen transmission rate (O_2TR) permitting to the raspberries with high respiration rates to receiveenough O_2 to prevent fermentation from occurring.

Fruit quality assessment

Weight losses (Figure 3) directly translates into a lower salable weight, progressively occurred in all samples during all the storage time but its rate was dependent both on the film used and the storage temperature. At low temperature (1±1°C) the highest weight losses were to the control.After 3 and 5 days of storage the weight losses of the control samples were respectively of 1.2% and 2.4 % while all fruits stored in MAP both with the F2 than F3 film (PB-F2, PB-F3, PLA-F2, PLA-F3, BA-F2, BA-F3) didn't exceed 1.1%. The water within berries is in equilibrium with the water vapor in the air so as the temperature increased and the relative humidity changed the moisture moved from inside the fruit to the outside air decreasing strongly the raspberry fruits weight. After 10 days and 13 days of storage fruits wrapped with the F3 film showed weight losses higher than F2 due the lowest performance barriers towards water vapour and gases and the BA-F3 sample reported the highest weight losses (%)(respectively 2.3 and 3.2%). Even when berries were subjected to metabolic stress due to the change of the temperature (Callesen and Møller Holm, 1989; Haffner et al., 2002; Siro et al., 2006) the found data showed that the weight loss was not a limiting factor for the quality of the raspberry. Grandeur® during storage. Raspberries as other soft fruits don't accumulate starch during the ripening but all samples showed increases in the values during the storage time. This was likely due to weight loss, which, although minimal (Figure 3), greatly affects the concentration of total soluble solids content (an estimate of sugar content) (Table 2). At harvest (0 days) the cv. Grandeaur® SSC was of 9.10 ± 0.12 °Brix and after storage it ranged from a minimum value of 9.33 to the maximum value of 9.90 °Brix (PLA-F2 and PB-F2 respectively). Statistically significant differences were detected among samples only after 3 and 13 days of storage. In the first case it was probably due to the high respiration rate of the raspberries near to the harvest time, while in the second case itwas due the residual effect of the high storage temperature that represents a stress for the raspberry fruits. The PLA- F3 and BA-F3 packages have better controlled the evolution of the SSC, showing respectively at the end of the storage, the lowest values (9.68 and 9.67 °Brix). About the titratable acidity (TA) was observed according to literature (Robbins et al.,1989; Haffner et al., 2002) values decrease if compared to the harvest values (18.39 meq/L). The TA decrease can influence the perceived sweetness of berries or it can result in bland flavor if the final concentrations are too low; after 13 days of storage the highest SSC/TA ratio (data not shown) was observed for the PLA-F3 sample. All the color parameters (L, Chroma, and Hue) were significantly affected by the packages and the storage time; up to 13 days overall values were reduced in comparison to the harvest time. According to Robbins and Moore (1990) increased differences were found between

Table 2. Changes in soluble solids content (SSC) (°Brix), titratable acidity (TA) (meq/L) and colour parametres (L,C,H) of raspberries cv. Grandeur®of differents packages.

Packages	Days											
	0	3			5			10			13	
SSC												
PB-F2		9.40	ab[1]	γ[2]	9.53	ns	βγ	9.73	ns	αβ	9.90	ab	α
PB-F3		9.43	ab	γ	9.53	ns	αβ	9.57	ns	αβ	9.70	ab	α
PLA-F2		9.33	b	β	9.50	ns	β	9.77	ns	α	9.93	a	α
PLA-F3	9.10 ± 0.12	9.37	b	γ	9.50	ns	βγ	9.57	ns	αβ	9.68	b	α
BA-F2		9.37	b	β	9.60	ns	αβ	9.70	ns	α	9.83	ab	α
BA-F3		9.37	b	ns	9.53	ns	ns	9.57	ns	ns	9.67	b	ns
Control		9.67	a	ns	9.77	ns	ns	_			_		
TA													
PB-F2		15.99	ab	αβ	15.78	a	β	15.81	c	β	17.25	a	α
PB-F3		16.78	ab	α	15.20	ab	β	16.75	ab	α	15.50	cd	β
PLA-F2		16.95	a	α	14.86	ab	β	15.74	c	β	15.40	cd	β
PLA-F3	18.39 ± 0.27	16.61	ab	β	14.34	b	γ	16.87	ab	α	16.01	bc	αβ
BA-F2		15.67	bc	γ	15.23	ab	γ	17.34	a	α	16.71	ab	β
BA-F3		14.48	c	β	15.82	a	α	16.11	bc	α	14.64	d	β
Control		13.10	d	α	11.42	c	β	_			_		
L													
PB-F2		29.82	b	α	29.67	b	α	27.18	c	β	25.10	a	γ
PB-F3		29.80	b	α	29.24	c	β	27.44	bc	γ	25.57	d	δ
PLA-F2		30.11	b	α	29.11	c	β	27.64	b	γ	27.09	b	δ
PLA-F3	33.9 ± 2.0	31.94	a	α	30.37	a	β	28.58	a	γ	28.74	a	γ
BA-F2		30.01	b	α	30.58	a	β	28.43	a	γ	27.09	b	δ
BA-F3		29.92	b	α	28.39	d	α	27.60	a	β	26.05	c	γ
Control		28.08	c	-	25.68	e	-	_			_		
C													
PB-F2		39.24	bc	α	37.59	c	β	35.79	b	γ	32.27	e	γ
PB-F3		39.04	cd	α	39.01	a	α	36.84	a	γ	37.70	a	β
PLA-F2		39.94	a	α	39.28	a	β	35.99	b	γ	35.03	d	δ
PLA-F3	42.9 ± 4.0	39.53	ab	α	38.96	a	β	35.90	b	γ	37.22	b	δ
BA-F2		39.91	a	α	38.32	b	β	36.06	b	γ	35.83	c	γ
BA-F3		38.67	d	α	37.26	c	α	33.07	c	β	32.46	a	γ
Control		34.10	e	-	31.26	d	-	_			_		
H													
PB-F2		0.47	c	α	0.46	c	β	0.44	a	γ	0.38	cd	δ
PB-F3		0.48	b	α	0.47	b	β	0.43	c	γ	0.39	bc	δ
PLA-F2		0.49	a	α	0.47	b	β	0.42	d	γ	0.38	d	δ
PLA-F3	0.5 ± 0.1	0.48	b	α	0.46	b	β	0.44	a	β	0.42	a	γ
BA-F2		0.49	b	α	0.48	a	α	0.43	b	β	0.32	e	γ
BA-F3		0.45	d	α	0.43	d	β	0.42	d	γ	0.40	b	δ
Control		0.42	e	-	0.39	e	-	_			_		

[1]The means in a column followed by different letters are significantly different at $p \leq 0.05$ according to Tukey's test. [2]The means in arow followed by different letters are significantly different at $p \leq 0.05$ according to Tukey's test.

the two storage temperature (1±1°C and 20±1°C) respectively at the end of 5 and 13 days of storage. L, C and H values of fruit stored at higher temperatures decreased faster than those stored at the lowest. Berries packaged with the macro-perforated film (F1) (control) lost more of their luminosity than berries packaged in MAP with L^* values of 28.08 and 25.58 respectively after 3 and 5 days of storage, meaning that the raspberries lost their brightred color during storage becoming darker. At both the temperatures the non commercial biodegradable and compostable films (F2, F3) influenced positively the evolution of the external colour of the berries due to the creation and the management of the MAP. According to previous work (Briano et al., in press) fruits stored in packages with the highest CO_2 concentration showed the highest L^* value. Statistically significantly difference were observed already after 3 days of storage for the PLA-F3 sample (31.94) that up to the end of storage showed the highest luminosity of the wrapped fruits (28.78). Similar to the L^* value, the same trend was found for the chroma and hue angle; they changed decreasing (fruits became less vivid) from the harvest time (42.9 and 0.5 respectively). After 5 days at 1±1°C the lowest values were observed for the macro-perforated film (F1) (control) due to the oxidative browning reactions which occur on fruits surfaces in the presence of O_2, while at the end of storage time (13 days) the PB-F3 and PLA- F3 showed similar C (32.77 and 35.83) and H values decreasing (0.38 and 0.37).

Conclusions

The quality of the raspberries cv. Grandeaur®in the post harvest supply chain was affected by the packaging materials and the storage temperatures both, but a single quality factor cannot be used to evaluate the best performance of packages. The loss of quality was very fast in the raspberries stored with the macro perfored film (F1) that have been maintained up to 5 days at the lowest temperature (1±1°C). The F2 and the F3 films maintained berries up to the end of storage (13 days) but results showed that the effect of MAP on the weight loss evolution wasn't significant due the high humidity inside the package. The retention of the inherent color of raspberry berries is often used as a quality indicator and it has a substantial impact on consumer acceptance (Del-Valle et al., 2005). Among all the bio packaging used the PLA–F3, best controlling the evolution of the SSC and keping berries quality colour more attractive, (especially at the highest storage temperature) could be introduced in the market of the raspberry's chain. To improve the use of this material in the fruit's supply chain furthermore, LCA analysis should support that this package is favorable from a sustainability point of view.

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