doi: 10.1016/j.foodchem.2017.12.067

Feasibility of biodegradable based packaging used for red meat storage during shelf-life: A pilot study

S. Panseri[a], P.A. Martino[b], P. Cagnardi[a], G. Celano[c], D. Tedesco[d], M. Castrica[a], C. Balzaretti[a], L.M. Chiesa[a]

[a] Department of Health, Animal Science and Food Safety, University of Milan, Via Celoria 10, 20133 Milan, Italy
[b] Department of Veterinary Medicine, University of Milan, Via Celoria 10, 20133 Milan, Italy
[c] Department of Veterinary Medicine University of Bari "A. Moro", Piazza Umberto I, 1, 70121 Bari, Italy
[d] Department of Environmental Science and Policy, Università degli Studi di Milano, Milan, Italy

Corresponding author.
E-mail address: sara.panseri@unimi.it (S. Panseri).

A B S T R A C T

This study was designated to ascertain the effectiveness of polylactic acid (PLA) based packaging solution to store red fresh meat during its refrigerated shelf-life. Recently the attention in the packaging industry regarding the use of bioplastics has been shifting from compostable/biodegradable materials toward biobased materials. Steaks obtained from semimembranous muscle of Piemontese beef were packaged in PLA trays closed with a lid made of PLA film and for comparison purposed in a conventional reference package consisting of a amorphous polyethylene terephthalate/polyethylene (APET/PET) trays and wrapped in plastic film of polyvinyl chloride (PVC). The packaging under modified atmosphere MAP was carried out by using a gas mixture of 66% O_2, 25% CO_2 and 9%N_2. By using PLA packaging combination it was possible to maintain an optimum red colour together with a reduced content of volatile compounds associated to off-flavours of meat samples particularly related to the oxidation phenomena.

Keywords: Polylactic acid (PLA), Biomaterials Packaging, Shelf-life, Red meat, Food safety

1. Introduction

The purpose of food packaging is to preserve the quality and safety of the food it contains from the time of manufacture to the time it is used by the consumer. An equally important function of packaging is to protect the product from physical, chemical, or biological damage (De Azeredo, 2009). This last represents a crucial role for perishable food like fresh meats. The most well-known packaging materials that meet these criteria are polyethylene- or co-polymer based materials, which have been in use by the food industry for over 50 years (Mahalik & Nambiar, 2010). The largest part of materials used in packaging in-dustries is produced from fossil fuels and are practically un-degradable. Recently the attention in the packaging industry regarding the use of bioplastics has been shifting from compostable/biodegradable mate-rials toward biobased materials (Nampoothiri, Nair, & John, 2010). Moreover, due to concerns about the environmental and health, con-sumers are avoiding the use of petroleum-based conventional packa-ging, which takes hundreds of years to decompose, and food products containing synthetic additives or preservatives (Nampoothiri et al., 2010).

PLA (polylactide) is a family of biodegradable thermoplastic polyester made from renewable resources which is nowadays seen as one of the most promising polymers for commercial use. It is produced by conversion of corn, or other carbohydrate sources, into dextrose, followed by fermentation into lactic acid. PLA exhibits tensile strength comparable to other commercially available polymers (Peelman et al., 2013). In addition to its strength, biodegradability, and compostability, PLA polymers also are resistant to oil-based products, are sealable at lower temperatures, and can act as flavour or odour barriers for food-stuffs (Sorrentino, Gorrasi, & Vittoria, 2007). This material shows good barrier to aroma but the most important limitation on the use of PLA for food application packaging is the medium barrier to gases and vapours and the brittleness properties (Gronman et al., 2013; Jamshidian et al., 2012). Moreover, considering that PLA is also classified as GRAS (Generally Recognized As Safe) by the American Food and Drug Administration (FDA) and is authorised by the European Commission (Commission Regulation No 10/2011), this polymer might be used in contact with food (Bishai, De, Adhikari, & Banerjee, 2014). It is important to un-derline that while some bio-based packaging materials may be biode-gradable, not all biodegradable materials are bio-based (Abdulkhani, Hosseinzadeh, Ashori, Dadashi, & Takzare, 2014). In consideration to the above mentioned reasons, PLA represent an excellent candidate for producing commercial compostable packaging materials. These mate-rials can be used to control the deterioration of perishable food pro-ducts, to maintain food quality and to extend the shelf life of foods as well (Detzel & Krüger, 2006). Meat represents one of the most perish-able foods in commerce and its safety and organoleptic properties may be altered during storage. These alterations may be due to different reactions such as microbial spoilage or oxidation processes that de-crease food value or produce unsafe food (Bastarrachea, Denis-Rohr, & Goddard, 2015). Generally, with the aim of preserving chilled meat from possible contaminations during storage, it is packaged on amor-phous polyethylene terephthalate in combination with polyethylene (APET-PET) trays and wrapped in plastic film of polyvinyl chloride (PVC) under modified atmosphere (MA) (Fonseca et al., 2015; McMillin, 2008; Smiddy, Papkovsky, & Kerry, 2002; Weng, van Niekerk, Neethirajan, & Warriner, 2016; Zhao, Lian, & Yue, 2013). With increasing consumer awareness and demand for fresh, safe, nutritious and healthy meat products, meat processors are continually in-vestigating new and innovative food preservation technologies for po-tential commercial application among which the bio-base packaging represent today an important investment field (Gao et al., 2017; Rizzolo et al., 2016).

Commercially available biopolymers in packaging have so far mainly been used for fruit and vegetable due to their relatively short shelf-life and respiration and humidity requirements. (Otoni, Espitia, Avena-Bustillos, & McHugh, 2016).

Currently, very little research exists to address the application of PLA to maintain the quality of muscle foods. Some studies have in-vestigated the effect of PLA, alone or in combination with other anti-microbials to inhibit microorganisms on fresh or further processed meat products (Chen & Brody, 2013; Rizzolo et al., 2016; Coma, 2008; Cutter, 2006; Kerry, O'Grady, & Hogan, 2006). In addition it was de-monstrated the synergistic effect of 2% low molecular weight polylactic acid alone or in combination with lactic acid or nisin against Escher-ichia coli O157:H7 on raw beef during irradiation and during re-frigerated storage (Chen & Brody, 2013; Coma, 2008). Considering the scarce information present in literature concerning the use of whole PLA packaging for meat storage, the purpose of this preliminary re-search was to investigate the feasibility of replacing APET/PE trays in combination to PVC film with biodegradable polymers PLA tray and film in order to preserve the quality traits of red meat as well as to control the microbial contamination during the refrigerated shelf-life.

2. Material and methods

2.1. Sampling and storage conditions

Sliced fresh top round beef, comprising the Semimembranous of Piemontese beef, were obtained from a local distribution store. The Piemontese is the most important double-muscle Italian autochthonous beef breed from the region of Piedmont, in north-west Italy. Its main attributes are a higher lean-to-fat ratio, a less marbled with less con-nective tissue red meat than other breeds and high tenderness. The Semimenbranous muscle was chosen as representing muscle of greatest mass and for its economic value and steaks used for the present study were cut (1 cm thick, 100 g weight). The pilot study was carried out at meat retail to simulate the real working conditions in order to obtain a real evaluation of performances in the context of real use of PLA ma-terial as a solution applicable to the packaging of red meat in a pro-tective atmosphere.

The steaks were packaged in thermoformed, transparent PLA trays with film thickness of 500 μm, closed with a lid made of 500 μm PLA film (ISAP Packaging Verona, Italy). PLA material characteristic was: elongation break (7.2%), tensile strength (36.4 MPa), decomposition temperature (200 °C) and half-life in 37 °C normal saline (4–6 months). For comparison purposed a conventional reference package consisting of a 420 μm amorphous polyethylene terephthalate/polyethylene (APET/PET) trays wrapped in plastic film of 120 μm polyvinyl chloride (PVC) were used (ISAP Packaging Verona, Italy).

The dimensions of all trays were 17.5 × 8 × 2.5 cm. The packaging under modified atmosphere MAP was carried out using a heat sealer Lari3/Pn Cavec T-VG-R-SKIN (Caveco, Milano, Italy). The gas mixture used to package all samples was composed by 66% O_2, 25% CO_2 and 9% N_2 (Aligal 49, Siad, Bergamo, Italy). All packs were stored at 4 ± 1 °C in order to simulate the retail conditions in a refrigerated chamber during the entire declared shelf-life (8 ± 1 days). To this purpose, this chamber was illuminated by a standard supermarket fluorescent lamp also. Two packages, with three samples each, were taken after 0, 2, 4, 6 and 8 days of storage for physico-chemical and microbiological analyses as well.

2.2. Microbiological analyses

Microbiological analyses were performed for evaluating of food safety parameters and the hygiene process indicator microorganisms.

In particular, enumeration of Mesophilic aerobic bacteria, enu-meration of Enterobacteriaceae, enumeration of coagulase-positive Staphylococci (CPS), enumeration of Escherichia coli, and the research of Salmonella spp. and Listeria monocytogenes were investigated. Furthermore, for monitoring the shelf life were evaluated the following parameters: total viable psychrophilic counts, Pseudomonas spp. counts and Total viable counts of Lactobacillus species.

The microbiological characteristics of a 10 g sample were obtained after homogenization in 90 mL of sterile diluent solution (0.85% NaCl and 0.1% peptone), and homogenized in a stomacher (Star Blender Digital- EUplug 710-0958) for 1 min at room temperature and then serial 10-fold dilutions were prepared in a sterile saline solution.

Mesophilic aerobic plate counts (APC) and Enterobacteriaceae plate counts were enumerated using a Petrifilm Aerobic Count (3M, St. Paul, Minnesota, USA), following the: AFNOR 3 M 01/1-09/89 and AFNOR 3 M 01/06-09/97 respectively. Petrifilm_ plates were also used to de-termine E. coli (EC), and CPS, in accordance with the following methods: AFNOR 3 M 01/08-06/01 and AFNOR 3 M 01/9-04/03 A, respectively.

Salmonella spp. detection (analytical unit: 25 g) was carried out using UNI EN ISO 6579: 2008 and the presence was confirmed by an API 20E system (Biomerieux, Marcy l'Etoile, France). The detection of L. monocytogenes (analytical unit: 25 g) was performed according to AFNOR BRD 07/4-09/98 (AFNOR, 2010a) and the presence was con-firmed according to the AOAC N.060402 (MID 67), 2010 method.

Total viable psychrophilic counts were evaluated by plating aliquots into plate count agar (PCA, OXOID Ltd., Basingstoke, and Hampshire, UK) the inoculated plates were incubated at 10 °C for 7 days.

Pseudomonas spp. counts were determined using Cephaloridine-Fucidin-Cetrimide selective medium (CFC, OXOID, Basingstoke, Hampshire, UK) and were incubated at 25° ± 1°C for 2 days. The presence was confirmed according to the ISO 13,720:2010 method.

Total viable counts of Lactobacillus species were determined using Man, Rogosa, and Sharpe (MRS, OXOID, Basingstoke, Hampshire, UK) agar and incubated at 30 °C ± 1 °C for 72 ± 3 h, according to the ISO 15,214:1998 method.

All results were expressed as log10 cfu g^{-1} and performed in du-plicate.

2.3. Physicochemical analyses

2.3.1. pH

The pH value of steaks was measured directly on the beef slices using a membrane glass probe type electrode (Crisolyt A, Crison PH meter GLP 22, Barcelona, ES).

2.3.2. Headspaces gas composition and oxygen transmission rate (OTR) of the packages

Analyses of CO_2 and O_2, expressed as percentage, within the packages were monitored by using a CheckMate 9000 gas analyser (PBI Dansensor, Ringsted, Denmark). The gas samples were taken with a needle inserted through a septum placed on the packages and measured in duplicate. The OTR of the empty packages were measured on sealed trays (APET and PLA) by the Ambient Oxygen Ingress Rate Method. The test conditions were 6°/80% relative humidity (HR) both dry (0% in-ternal humidity) and wet gas (100% internal humidity) inside the packages. Wet gas was obtained by adding 10 mL water to the packages. Results were calculated as mL/package (mean values of four samples).

2.3.3. Colour measurements

The colour evolution of the individual meat samples stored in the two different packages was determined on the basis of the values of the CIELab system of coordinates immediately following the performance of sensory assessment. The measuring procedure was according to O'Sullivan & Kerry, 2013. The parameters of the color space L – lightness, a – redness and b – yellowness were measured six times for each sample by the reflectance method using a Konica Minolta CM-5 Spectrophotometer (Konica Minolta Sensing, Inc., Japan). The Hue angle was calculated as $\mathrm{Tan}^{-1}(b/a)$. The instrument was calibrated to white and a setting with D65 light source and measurement slit of 8 mm was used. Colour measurements were performed directly after opening the package since consumers buying case-ready packaged beef evaluate its colour at the point of sale, with no blooming.

2.4. Volatile compounds analysis

2.4.1. HS-SPME extraction of volatile compounds

The volatile compounds investigated in the preset study were se-lected on the basis of their primarily impact on the sensory changes as well as chemical oxidation phenomena occurring during the shelf-life of red meat as already investigated and observed in our previous studies as well (hexanal, 3-hidroxy-2-propanone and acetic acid) (Chiesa, Soncin, Biondi, Cattaneo, & Cantoni, 2006; Panseri, Chiesa, Zecconi, Soncini, & De Noni, 2014; Soncin, Chiesa, Cantoni, & Biondi, 2007).

10 g minced meat samples and 10 μl of internal standard solution (4-methyl-2-pentanone; 20 μg mL-1) were weighed into 20 mL headspace vials and sealed with polytetrafluoroethylene (PTFE)-coated silicone rubber septa (20 mm diameter) (Supelco, Bellefonte, PA, USA). The vials were kept at 7 ± 1 °C for at least 1 h to allow the volatile com-pounds in the headspace above the sample to reach equilibrium. At the end of the sample equilibration time, a conditioned (1.5 h at 280 °C) 85 μm Carboxen/polydimethylsiloxane (CAR/PDMS) StableFlex fibre (Supelco, Bellefonte, PA, USA) was exposed to the headspace of the sample for volatile compounds extraction (90 min at 25 ± 2 °C) by CombiPAL system injector autosampler (CTC Analytics, Zwingen, Switzerland). These conditions have already been reported (Chiesa et al., 2006).

2.4.2. GC/MS conditions

Analyses were performed with a TraceGC (Ultra gas chromatograph (Thermo Fisher Scientific, Rodano, Italy) equipped with an Rtx-WAX column (30 m × 0.25 mm i.d., 0.25 μm film thickness; Superchrom, Milan, Italy) and coupled to a TraceDSQII mass spectrometer (Thermo Fisher Scientific) with source and transfer line temperatures kept at 250 and 200 °C respectively. The column temperature was set initially at 35 °C for 8 min, then increased to 60 °C at 4 °C $min^{-1,}$ to 160 °C at 6 °C min^{-1} and finally to 200 °C at 20 °C min^{-1} and held for 15 min. Helium was used as the carrier gas at flow rate of 1 mL min^{-1}. The injector temperature was set at 220 °C. The splitless mode was used for injection, with a purge time of 8 min. The fibre was maintained in the injection port for 8 min. Electron ionization masses were recorded at 70 eV in the mass range between m/z 35 and 350. After each analysis the fibre was routinely desorbed at 250 °C for 15 min in order to eliminate high-boiling-point contaminants. The identification of the volatile compounds was carried out by comparing their mass spectra with those of standard compounds when available, or by comparing their mass spectra with those stored in the National Institute of Standards and Technology (NIST) US Government Library and with Wiley spectral databases. Analyses were performed in triplicate. Results were expressed as ng g^{-1} internal standard equivalents.

2.5. Consumers sensory evaluation

Consumer panellists were utilized to detect differences in sensory attributes of beef stored in the two different packaging (colour, odour and overall acceptability). The consumers' panel was constituted by 10 elements from the staff of the Veterinary institute of Milan– food safety laboratory (aged between 19 and 64 years old) with previous training during two sessions evaluating the sensory attributes as well. Each sensory attribute was rated on a continuous linear scale ranging from 0 (no perception of the descriptor) to 9 (very intense). The testers were asked to test the samples for the following characteristics: colour intensity, acid odour. The panellists were also asked to express their preference (overall acceptability) by scoring the samples with a 0–9 scale, on which 0 corresponded to “dislike very much” and 9 corre-sponded to “like very much”. In particular, odour panels were con-ducted on packaged removed from the case at each sampling intervals. The packages were opened in a random order and panellist were al-lowed to smell the patties without touching them. Off-odours were assessed within 30 s of package opening also. During the evaluation, the panellists had free access to water and unsalted bread.

2.6. Statistical analysis

Analysis of variance (ANOVA) was performed to assess differences between the investigated VOCs, microbiological and chemical para-meters of meat samples stored in the two different packaging. $p < .05$ was considered to be significant. Statistical analysis was conducted with SPSS software (version 17.0, SPSS, Chicago, ILL).

3. Results and discussion

The quality of fresh meat depends on several quality indices, which can be clustered in two main groups: chemical-sensory and micro-biological, the meat colour or its appearance is one of the most im-portant attributes for red meat whereas the microbiological indices account for its safety. The results are summarised in the following paragraphs.

3.1. Gas-composition trend

The headspace gas composition of a fresh meat package changes dynamically as the dominant gases, oxygen and carbon dioxide can be produced or removed through respiration, oxidation, solubilization and permeation processes as well. These phenomena are in function of the packaged food and can be influences from the packaging materials also (Gao et al., 2017).

The measured percentages of O_2 and CO_2 into the two typologies of investigate packaging solution during the refrigerated shelf-life of red meat samples were shown in Fig. 1. Respect to the storage times we observed a general decrease of CO_2 percentage. A general drop in CO_2 content is expected because of CO_2 adsorption into the meat samples and due to the packaging material transmission of CO_2 also as reported by other authors (Chen & Brody, 2013; Rizzolo et al., 2016). For the traditional material the minimum level was reached at 8 days with very little variation during the shelf-life in contrast with PLA packaging system in which a considerably large decreasing was observed reaching the minimum at day 8. The two materials clearly and statistically differ in CO_2 loss this last higher for the PLA packages than the reference material as well. Generally, carbon dioxide is generated through re-spiration and reduced when being dissolved in the meat or when per-meating through the packaging material to the external atmosphere. This decline cannot be monitored by reason of microbial growth. Regarding O_2 percentages, statistically difference were also noted for the two packages with opposite behavior. In meat stored in PLA packages an increasing of O_2 was evident during the entire shelf-life. The higher rate of oxygen permeation for PLA must be attributed to the higher OTR of this type of packaging compared to the reference (Table S1). In general, this high rate of oxygen accumulation in the PLA packages could represent a limit and not compatible with the desired

MA with a low concentration of oxygen (f.e for cheese storage) in which low oxygen concentration is usually used (Coma, 2008; Zhao et al., 2013). The barrier properties of plastic materials use for packaging play a major role in determining the shelf-life of packaged foodstuffs. In par-ticular polymeric films, controlling the rate at which small molecular weight compounds permeate in or out of the package, can slow down the detrimental phenomena responsible for the unacceptability of the packaged foods (Jamshidian et al., 2012; Sorrentino et al., 2007).

3.2. Microbiological results

The microbiological results are presented in Table S2, the data for both samples (meat in PLA package and meat in PET/PE package) are expressed in relation to the evaluation after 0, 2, 4, 6 and 8 days of storage at 4 °C ± 1 °C.

The results expressed as Log CFU/g, while for the Salmonella spp. and Listeria monocytogenes parameters the absence are expressed in 25 g samples.

The results show that there are not significant variations in the value of all microbiological parameters investigated, during the re-frigerated storage in both samples, as shown in Figs. 5 and 6.

3.3. pH trend

The evolution of pH values with respect to time and type of packaging is shown in Fig. S3. As we observed no statically difference were detected both during the shelf life and examining the two packaging solutions adopted for red meat storage.

3.4. Instrumental color analysis

The cherry red color in meat is one of the most important qualities influencing the consumer's decisions to purchase (McMillin, 2008). The color of meat depends on many factors, such as the concentration and chemical state of heme pigments, particularly myoglobin; the physical characteristics of the meat; and the pH (McMillin, 2008). Discoloration results from the conversion of oxymyoglobin to metmyoglobin, which produces an unattractive brown color (Coma, 2008).

Also packaging materials as well as mixture gas composition in MA are critical factors influencing the color of red meat during the shelf-life (Coma, 2008). Lightness (L), redness (a) and yellowness (b) were measured and then used to calculate the Hue index. Hue value (low value indicate red color, whereas high values indicate yellow color) measured during the shelf-life is presented in Fig. 2. Generally an increasing during the shelf-life was observed in the two different packaging systems during the shelf life. The increase of this parameter depends on the storage temperature and time as reported by other authors and it could be explained by the gradual oxidation of myoglobin and accumulation of metmyoglobin with time. As reported in Fig. 2 we observed a statically difference between red meat samples stored in the reference packaging and PLA, these last with more low value suggesting the hue variations during storage dependent on the nature of the packaging investigated. These results confirmed the PLA based packaging as suitable material to maintain the red cherry color in refrigerated red meat during its the entire shelf-life as well.

3.5. Volatile compounds analysis

The trend of the investigated volatile compound during the shelf-life of meat sample stored in different packaging is presented in Fig. 3. A statically difference were observed after 6 day storage along with an increasing of volatile compounds associated to the oxidation phe-nomena (hexanal and hidroxy-2-butanone-acetoin) in the samples stored in reference packaging. Moreover, only some volatile com-pounds, defined as aroma compounds, are important for the char-acterisation of a product's aroma; indeed, some compounds with a very low odour threshold have an important impact on the formation of the "aromatic fingerprint" of the product in particular for meats. Usually the development of oxidative off-flavour (rancidity) has long been re-cognized as a serious problem during the storage of meat products. Hexanal is mainly formed during the oxidation of linoleic acid via the 13-hydroperoxide. It has an odour described as "grassy" which con-tributes to off-flavour, due to the low odour threshold in water: (4,5 μg kg^{-1}) (Bianchi et al., 2007; Turchini et al., 2005).

In addition high O_2 atmosphere concentration tends to favor lipid oxidation of red meat. The use of high concentration of O_2 usually up of 70% is however necessary in order to transform myoglobin, purple in color, to its oxygenated form of oxymyolobin, bright red in color. In our experiment we observed a different trend of hexanal which was de-veloped in minor concentration in red meat samples packaged in bio based PLA packaging. Similar trend was shown for acetoin with minor concentration detected in meat stored in PLA trays. Acetoin together
with acetic acid are derived entirely from the catabolism carbohydrates. Under aerobic conditions, microorganisms such as B. thermosphacta produces acetoin; acetic, and other volatile compounds among which acetoin is the volatile compounds strictly related to the sour-sweet offensive odour. Oxygen and carbon dioxide mainly affected glucose metabolism (Chen & Brody, 2013). Under aerobic conditions, this organism produces acetoin from diacetyl, which comes from pyruvate via -acetolactate, yielding one molecule of acetoin per molecule of glucose, while under anaerobic conditions it transforms glucose mainly into lactic acid, yielding two molecules of lactic acid per molecule of glucose as well (Chen & Brody, 2013).

No significantly, differences were shown for acetic acid concentra-tion's trend in the meat sample stored in the two investigated packaging this also supported from a constant trend of pH during the entire shelf-life.

3.6. Sensory changes

Sensory properties concerning the evaluation of red colour, acidity and overall acceptability were show in Fig. 4. Based on data displayed in Fig. 4b is evident that the meat samples stored in PLA packaging maintained a red colour longer than meat stored in reference packaging material. In addition also acidy score were judged lower in meat packaged in PLA (Fig. 4a). As consequence, the overall acceptability of meat in PLA tray was defined as sufficient at day 9 of the shelf-life in contrast with meat stored in reference material reaching the sufficient value at day 7. This is important evidence that could allow and led to propose an extension shelf-life of about two days. These results are in accordance with Pettersen, Bardet, Nilsen, & Fredriksen, 2011 that in-vestigated the use of PLA material to store fresh salmon compared with APE/PET packaging. The author found a significantly higher score va-lues concerning colour intensity and acceptability in fillet stored in PLA packaging for the entire shelf-life.

4. Conclusions

In the present pilot study two different kinds of options for beef steak packagings are evaluated on the basis of their ability to preserve and maintain quality of meat along shelf-life. The studied options were bio-based polylactic acid packaging and fossil based amorphous poly-ethylene terephthalate/polyethylene + PVC combination. Different parameters were investigated to obtain information toward the feasi-bility of potential use of PLA to preserve the quality of red meat.

This represents the first study that involves the use of a packaging solution in which both tray and film are made of PLA. The quality of fresh meat depends on several quality indices, which can be clustered in two main groups: chemical-sensory and microbiological. Microbiological analyses in particular related to the shelf-life con-sidering total viable psychrophilic counts, Pseudomonas spp. counts and total viable counts of Lactobacillus species showed the same behaviour in meat packaged in PLA compared to meat stored in conventional packaging system. Examining the evaluation of colour, that represents a crucial parameter conditioning the consumer, statically difference were shown between red meat samples stored in the reference packaging and PLA, these last with more low Hue value. These results confirmed the PLA based packaging as suitable material to preserve the red cherry color in refrigerated red meat during its the entire shelf-life as well. These results are then in accordance with consumer evaluations that revealed meat samples stored in PLA packaging maintained a red colour longer than meat stored in reference packaging material. Acidy score were judged lower in meat packaged in PLA also. It is important to underline how new high-performance materials, energy efficient pro-duction technologies, protective solutions for preservation and insula-tion are just a few of the current technological challenges to avoid food waste. Bio-based packaging represent an integrated approach, from design to communication to disposal, which takes into account all the steps of a product generation process, making the most of each of them and of all the parties involved, in view of implementing a virtuos cir-cular economy. The results obtained from the present pilot study on the feasibility of potential use of bio based packaging material PLA for red meat storage along the declared shelf-life confirm the efficacy of this material for red meat storage.

Acknowledgment

The present study was supported by ISAP Packaging, Verona, Italy and Compac, Reggio Emilia, Italy.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.foodchem.2017.12.067.

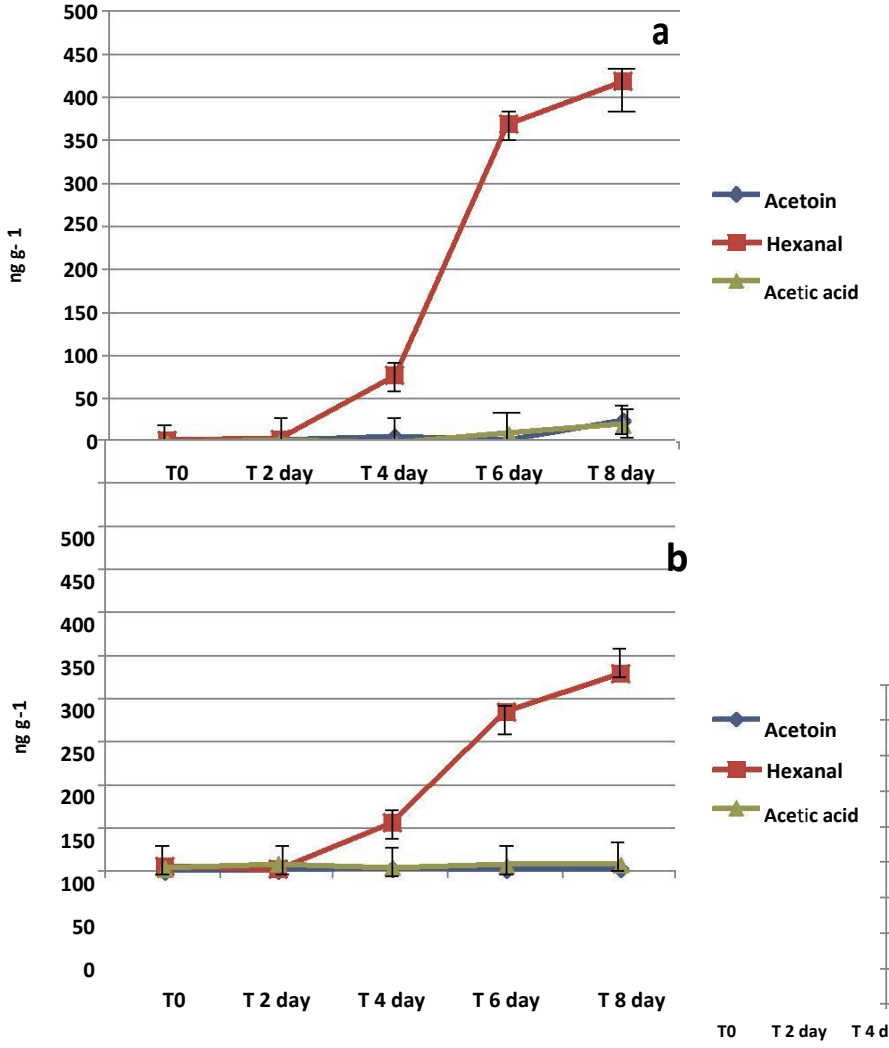
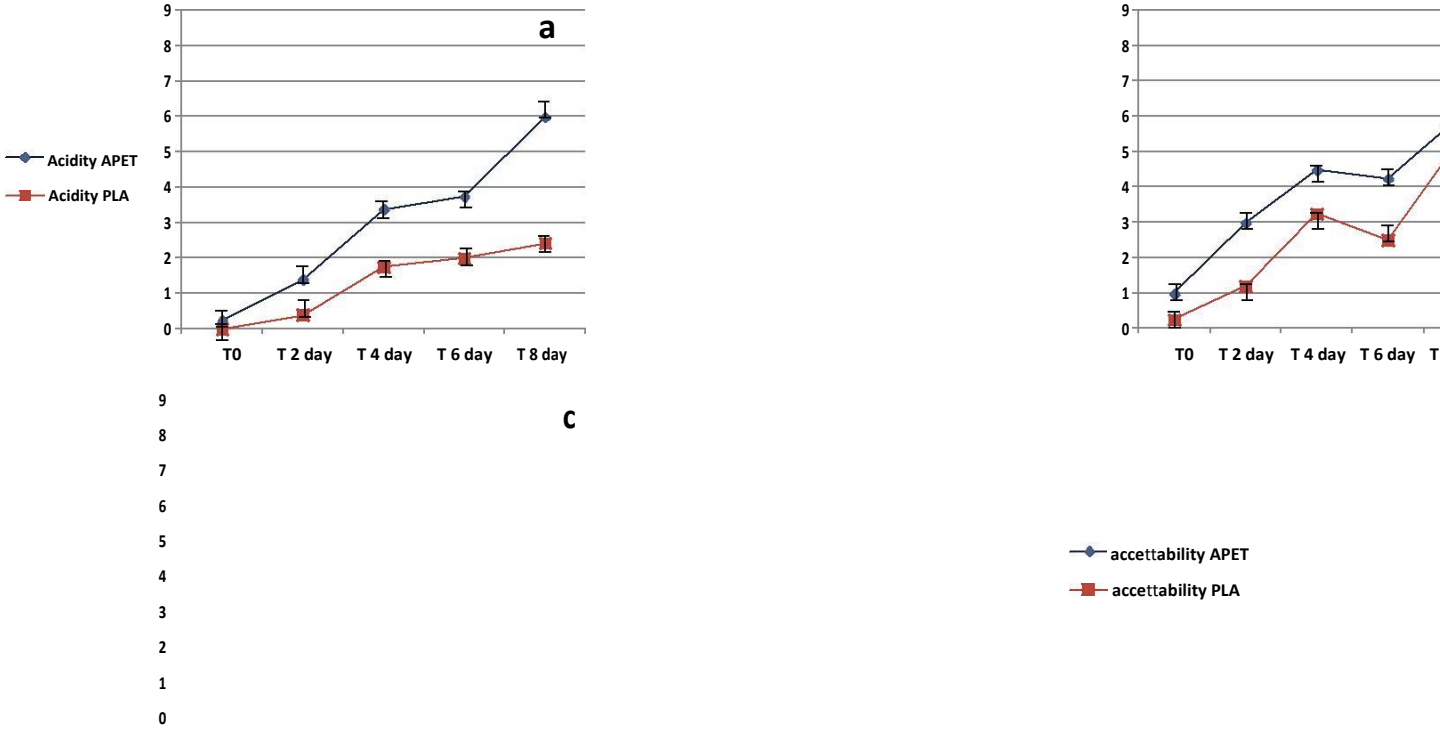


Fig. 3. Evolution of Volatile compounds associated to oxidation phenomena during the refrigerated shelf-life of meat samples stored APET (a) and PLA (b) typologies.



color intensity PLA

color intensity APET

Fig. 4. Evolution of sensory parameters during the refrigerated shelf-life of meat samples stored in two packaging typologies (APET and PLA).

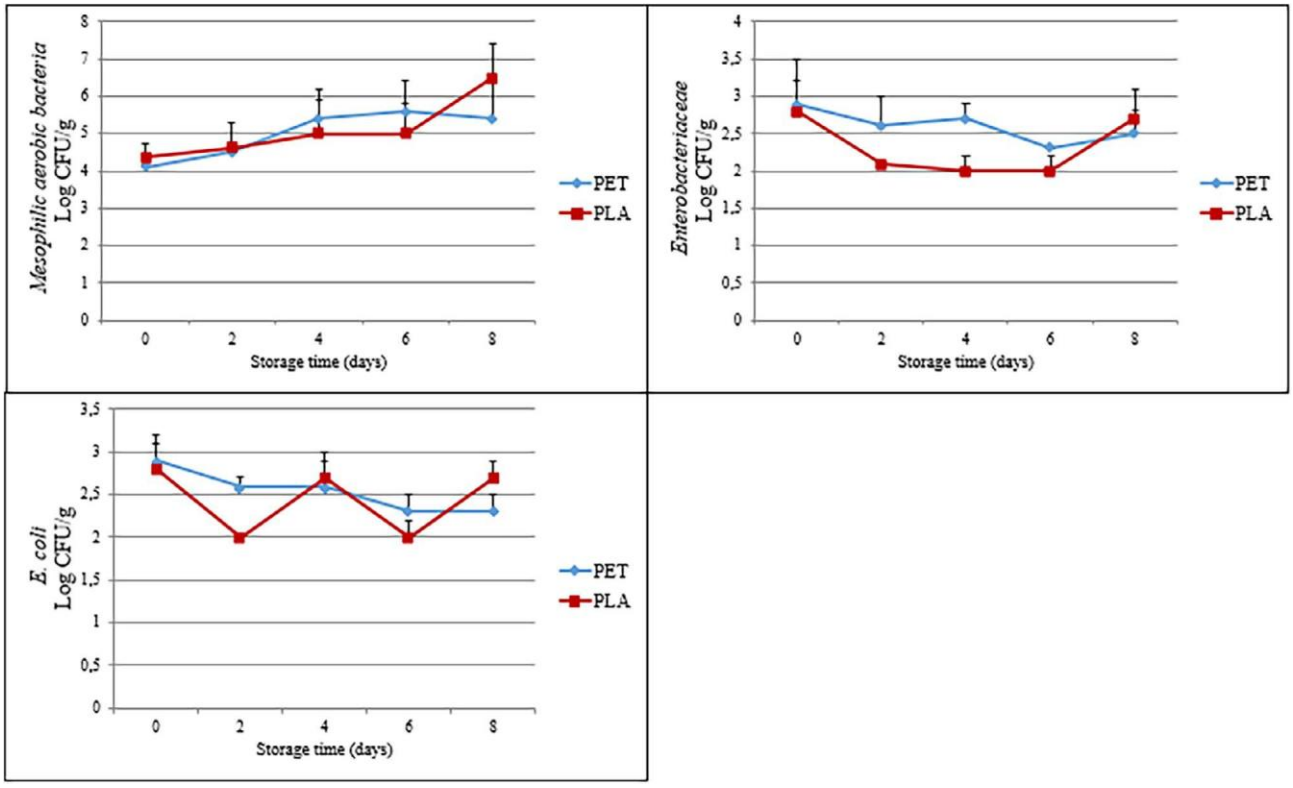


Fig. 5. Count of Mesophilic aerobic, Enterobacteriaceae and E. coli during the refrigerated shelf-life of meat samples stored in two packaging typologies (APET and PLA).

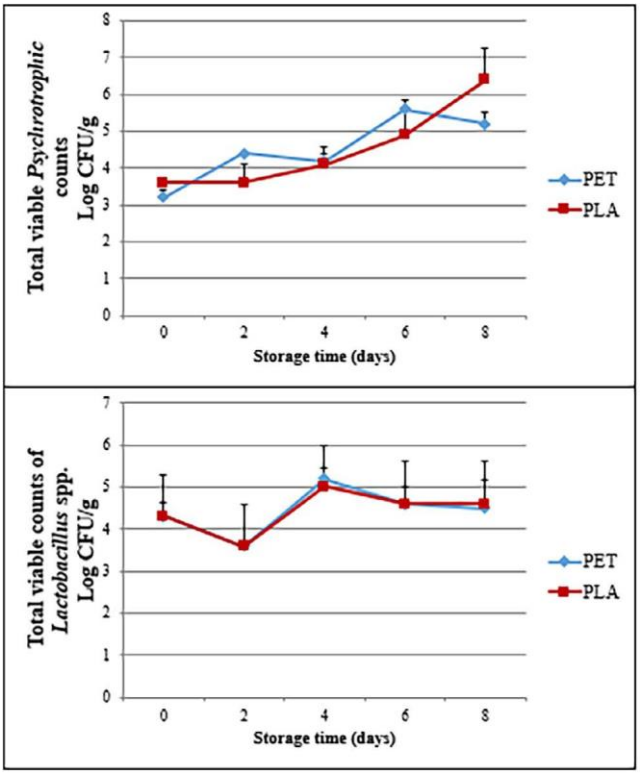


Fig. 6. Count of total viable psychrophilic and Lactobacillus spp. during the refrigerated shelf-life of meat samples stored in two packaging typologies (APET and PLA).

References

Abdulkhani, A., Hosseinzadeh, J., Ashori, A., Dadashi, S., & Takzare, Z. (2014). Preparation and characterization of modified cellulose nanofibers reinforced poly-lactic acid nanocomposite. Polymer Testing, 35, 73–79.

Bastarrachea, L. J., Denis-Rohr, A., & Goddard, J. M. (2015). Antimicrobial food equip-ment coatings: Applications and challenges. Annual Review of Food Science and Technology, 6, 97–118.

Bianchi, F., Cantoni, C., Careri, M., Chiesa, L., Musci, M., & Pinna, A. (2007). Characterization of the aromatic profile for the authentication and differentiation of typical Italian dry-sausage. Talanta, 72, 1552–1563.

Bishai, M., De, S., Adhikari, B., & Banerjee, R. (2014). A comprehensive study on en-hanced characteristics of modified polylactic acid based versatile biopolymer. European Polymer Journal, 54, 52–61.

Chen, J., & Brody, A. L. (2013). Use of active packaging structures to control the microbial quality of a ready-to-eat meat product. Food Control, 30, 306–310.

Chiesa, L. M., Soncin, S., Biondi, P. A., Cattaneo, P., & Cantoni, C. (2006). Different fibres for the analysis of volatile compounds in processed meat products by solid phase micro-extraction (SPME). Veterinary Research Communication, 30, 349–351.

Coma, V. (2008). Bioactive packaging technologies for extended shelf life of meat based products. Meat Science, 78, 90–103.

Cutter, C. N. (2006). Opportunities for bio-based packaging technologies to improve the quality and safety of fresh and further processed muscle foods. Meat Science, 74(1), 131–142.

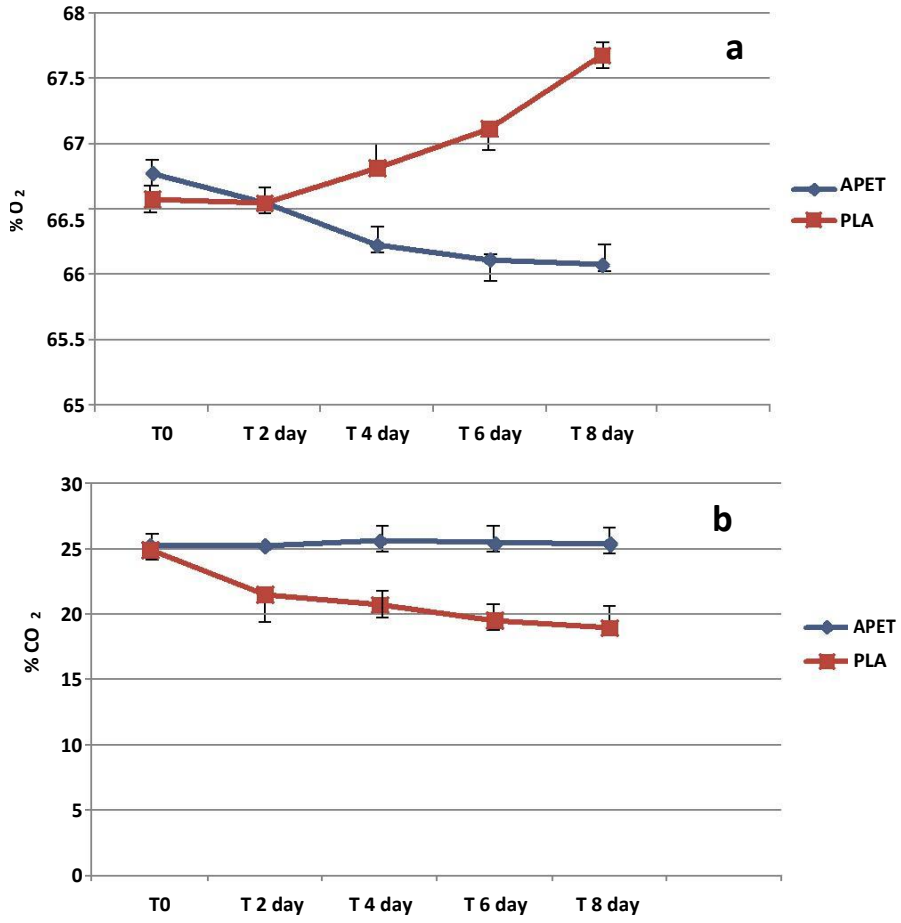
De Azeredo, H. M. C. (2009). Nanocomposites for food packaging applications. Food Research International, 42(9), 1240–1253.

Detzel, A., & Krüger, M. (2006). Life cycle assessment of PLA: A comparison of food packaging made from NatureWorks® PLA and alternative materials.

Fonseca, C., Ochoa, A., Ulloa, M. T., Alvarez, E., Canales, D., & Zapata, P. A. (2015). Poly (lactic acid)/TiO2 nanocomposites as alternative biocidal and antifungal materials.

Materials Science and Engineering: C, 57, 314–320.
Gao, H., Fang, X., Chen, H., Qin, Y., Xu, F., & Jin, T. Z. (2017). Physiochemical properties and food application of antimicrobial PLA film. Food Control, 73, 1522–1531.
Gronman, K., Soukka, R., Jarvi-Kaariainen, T., Katajajuuri, J. M., Kuisma, M., Koivupuro, H. K., et al. (2013). Framework for sustainable food packaging design. Packaging Technology and Science, 26(4), 187–200.
Jamshidian, M., Tehrany, E. A., Imran, M., Akhtar, M. J., Cleymand, F., & Desobry, S. (2012). Structural, mechanical and barrier properties of active PLA-antioxidant films. Journal of Food Engineering, 110(3), 380–389.
Kerry, J. P., O'Grady, M. N., & Hogan, S. A. (2006). Past, current and potential utilisation of active and intelligent packaging systems for meat and muscle-based products: A review. Meat Science, 11, 113–130.
Mahalik, N. P., & Nambiar, A. N. (2010). Trends in food packaging and manufacturing systems and technology. Trends in Food Science & Technology, 21(3), 117–128.
McMillin, K. W. (2008). Where is MAP Going? A review and future potential of modified atmosphere packaging for meat. Meat Science, 80, 43–65.
Nampoothiri, K. M., Nair, N. R., & John, R. P. (2010). An overview of the recent devel-opments in polylactide (PLA) research. Bioresource Technology, 101(22), 8493–8501.
Otoni, C. G., Espitia, P. J. P., Avena-Bustillos, R. J., & McHugh, T. H. (2016). Trends in antimicrobial food packaging systems: Emitting sachets and absorbent pads. Food Research International, 83, 60–73.
Panseri, S., Chiesa, L. M., Zecconi, A., Soncini, G., & De Noni, I. (2014). Determination of volatile organic compounds (VOCs) from wrapping films and wrapped PDO Italian cheeses by using HS-SPME and GC-MS. Molecules, 19, 8707–8724.
Peelman, N., Ragaert, P., De Meulenaer, B., Adons, D., Peeters, R., Cardon, L., et al. (2013). Application of bioplastics for food packaging. Trends in Food Science & Technology, 32(2), 128–141.
Pettersen, M. K., Bardet, S., Nilsen, J., & Fredriksen, S. B. (2011). Evaluation and suit-ability of biomaterials for modified atmosphere packaging of fresh salmon fillets. Packaging Technology and Science, 24(4), 237–248.
Regulation (EU) No 10/2011 of 14 January 2011 on plastic materials and articles in-tended to come into contact with food Text with EEA relevance.
Rizzolo, A., Bianchia, G., Povolob, M., Miglioria, C. A., Contarinib, G., Pelizzolab, V., et al. (2016). Volatile compound composition and antioxidant activity of cooked ham slices packed in propolis-based active packaging. Food Packaging and Shelf Life, 8, 41–49.
Smiddy, M., Papkovsky, D. B., & Kerry, J. P. (2002). Evaluation of oxygen content in commercial modified atmosphere packs (MAP) of processed cooked meats. Food Research International, 35, 571–575.
Soncin, S., Chiesa, L. M., Cantoni, C., & Biondi, P. A. (2007). Preliminary study of the volatile fraction in the raw meat of pork, duck and goose. Journal of Food Composition and Analysis, 20, 436–439.
Sorrentino, A., Gorrasi, G., & Vittoria, V. (2007). Potential perspectives of bionano-composites for food packaging applications. Trends in Food Science and Technology, 18, 84–95.
Turchini, G. M., Mentasti, T., Caprino, F., Giani, I., Panseri, S., Bellagamba, F., ... Valfré, F. (2005). The relative absorption of fatty acids in brown trout (Salmo trutta) fed a commercial extruded pellet coated with different lipid sources. Italian Journal of Animal Science, 4(3), 241–252.
Weng, X., van Niekerk, J., Neethirajan, S., & Warriner, K. (2016). Characterization of antimicrobial efficacy of photocatalytic polymers against foodborne biofilms. LWT-Food Science and Technology, 68, 1–7.
Zhao, Y., Lian, Z., & Yue, J. (2013). Recent development in food Packaging, a review. Journal of Chinese Institute of Food Science and Technology, 13(4), 1–10.

Fig. 1. Evolution of O_2 (a) and CO_2 (b) percentage during the refrigerated shelf-life of meat samples stored in two packaging typologies (APET and PLA).



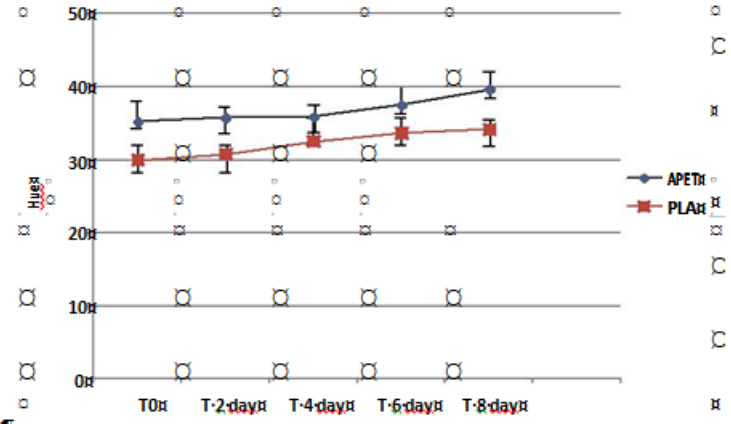


Fig. 2. Hue angle modification during the refrigerated shelf-life of meat samples stored in two packaging typologies (APET and PLA).