Food Chemistry 371 (2022) 131134

Contents lists available at ScienceDirect

Food Chemistry

journal homepage: www.elsevier.com/locate/foodchem

A shelf-life study for the evaluation of a new biopackaging to preserve the quality of organic chicken meat

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ARTICLE INFO

Keywords:
Biopackaging
organic chicken
biogenic amines
volatile organic compounds
shelf life

ABSTRACT

Widespread use of traditional packaging constitutes a serious ecological problem leading to a shift to biodegradable and compostable materials. The aim of this work is to study the ability of a new biopackaging (BP), based on biodegradable and compostable material, to preserve the quality of organic chicken meat for 14 days in comparison with a polyethylene terephthalate (PET) material. Results showed that the indices of Biogenic Amines (BAs) and the 18 monitored Volatile Organic Compounds (VOCs) have a similar trend in both packaged meats. For example, the total BAs concentration in meat increased from 390 to 961 mg Kg^{-1} in BP and from 393 to 800 mg Kg^{-1} in PET, as well as the microbiological counts. The new biopackaging (BP) showed similar properties of non-biodegradable material (PET) to preserve the shelf life of organic chicken meat and it could be used instead of plastic materials to promote a circular economy.

1. Introduction

The global awareness of the environmental issues associated with the use of synthetic and non-degradable packaging has led to an increased interest in biopackaging based on biodegradable and natural polymers (Ganesh Kumar, Anjana, Hinduja, Sujitha, & Dharani, 2020). Biopackaging is thus a growing sector in terms of innovation, to face the sustainability challenges of the food packaging industry (Bajer, Janczak & Bajer, 2020).

Indeed, biodegradable polymers offer a possible alternative to traditional non-biodegradable plastics when recycling is impractical or not economical (Magni et al., 2020). Compostable food packaging can solve the disposal problems of difficult-to-recycle plastic packaging, avoiding their disposal in landfills or incineration. At the same time, compostable food packaging allows the enhancement of organic waste, which, if properly treated, can generate quality compost to restore soil nutrition (Markus & Ramani, 2021).

Among the biopolymeric materials used for biopackaging applications, polysaccharides such as cellulose, alginate, gelatin have been proposed. More recently, chitosan has been the most explored polysaccharide material for the development of biodegradable packaging (Díaz-Montes & Castro-Muñoz, 2021a). Beyond polysaccharide-based materials, various studies proposed the use of proteins-based biopolymers (gluten, whey proteins, or casein) and lipids biopolymers (waxes, oils, free fatty acids). Moreover, biopackaging can be formulated with biopolymers synthesized from bioderived monomers (polylactic acid, polyesters) or produced directly from microorganisms (polyhydroxyalkanoate, polyhydroxybutyrate) (Chen et al., 2019; Díaz-Montes & Castro-Muñoz, 2021b).

However, from all the proposed materials, starch is the most used biopolymer for biopackaging formulation due to its mechanical properties close to those of traditional plastics like polyethylene and polystyrene (Jiang, Duan, Zhu, Liu & Yu, 2020). Nowadays, studying biopackaging and monitoring their quality to reduce economic loss and

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https://doi.org/10.1016/j.foodchem.2021.131134
Received 26 January 2021; Received in revised form 24 August 2021; Accepted 13 September 2021
Available online 15 September 2021

food waste is more important than ever. Therefore, a key challenge is to assess the performance of biopackaging like starch-based packaging in preserving food quality during storage, especially easily perishable products.

The preservation of quality and appearance of perishable food, such as raw meat, is essential during its distribution and merchandising. According to FAO, world poultry meat production soared from 9 to 122 million tonnes between 1961 and 2017, and in 2017, poultry meat represented about 37 % of global meat production, with chickens contributing 89 % of world poultry meat production (FAO, 2020). Among different systems, organic production has notably increased in importance over recent years (Rabadán et al., 2020). The percentage of surface area dedicated to organic production has doubled in the last ten years (FIBL-IFOAM, 2019).

Several factors affect meat shelf-life, such as the presence of oxygen, storage temperature, endogenous enzymes, exposure to light, and microorganisms, leading to deterioration and reduction of meat shelf life (Stopforth, 2017). Microbial deterioration, lipid oxidation, and autolytic enzymatic spoilage are the three main mechanisms for fresh meat spoilage. The spoilage processes lead to pH changes, appearance changes, slime formation, structural component degradation, which can cause the production of biogenic amines and volatile organic compounds (Dave & Ghaly, 2011). Off-odors released from meat during storage might suitably act as food freshness/spoilage indicators. Moreover, a sensory evaluation can be used to assess the deterioration of meat organoleptic characteristics. For example, the meat aspect is generally considered as the most important factor that affects consumer purchase (Sharif, Butt, Sharif, & Nasir, 2017).

Currently, few studies have been performed on the application of starch-based biopackaging to maintain the quality of fresh meat. Research has been focused on the degradation, ecotoxicity, environmental impact, and mechanical characteristics of biopackaging materials (Johnson, Tucker & Barnes, 2003; Scaffaro, Morreale, Lo Re & La Mantia, 2009; Magni et al. 2020). Therefore, this study aims to assess the ability of a new biopackaging to preserve the quality of organic chicken meat in comparison to classic polyethylene terephthalate packaging. This objective was achieved through the monitoring of chemical (biogenic amines, volatile organic compounds) and microbiological (meat microbiota) markers as well as sensorial parameters of packaged organic chicken breast meat.

2. Materials and methods

2.1. Packaging materials

The studied biopackaging (BP) consists of a completely biodegradable and compostable tray and film. The material used for BP is provided by Novamont (Novara, Italy). This material is obtained by means of Novamont's proprietary technologies, using bio-polyesters obtained by polycondensations of diacids and diol. The result is a compostable multilayer structure constituted by Novamont's bio-polymers. The geometry of the products are: a) film: weight 1,5 g, thickness 39 μm, (l1 × l2) 23 × 14,5 cm, b) tray: weight 23,5 g, thickness 600–700 μm; (l1 × l2 × h) 23 × 14,5 × 4 cm (Fig. 1S).

The packaging used for comparison consists of a traditional polyethylene terephthalate (PET) packaging (PET-EL L1523-27 TR1160000 O2WH, Linpac Packaging Pravia, Spain) combined with a cryovack film (LID 830X, Sealed Air Food Care, Charlotte, USA).

2.2. Sample collection

Fileni® industry (Cingoli, Italy) provided fresh organic chicken breast meat packaged with new BP composed by biodegradable and compostable tray and film. The same fresh organic chicken breast meat was wrapped with PET packaging combined with a cryovack film. All samples were wrapped in a modified atmosphere (MAP) (70% O_2, 20% CO_2, and 10% N_2). Analyses were performed on chicken breast meat at day 0, day 3, day 6, day 10, and day 14, every time opening a new pack. During the analysis period, samples were held at 4 °C to simulate the consumer storage conditions. All analyses were performed in triplicate.

2.3. Chemicals and reagents

Spermine tetrahydrochloride (SPM, $C_{10}H_{26}N_4{\cdot}4HCl$, >98%), spermidine trihydrochloride (SPD, $C_7H_{17}N_3{\cdot}3HCl$, >98%), cadaverine dihydrochloride (CAD, $C_5H_{14}N_2{\cdot}2HCl$, >98%), putrescine dihydrochloride (PUT, $C_4H_{12}N_2{\cdot}2HCl$, >98%,), histamine dihydrochloride (HIS, $C_5H_9N_3{\cdot}2HCl$, >99%), tyramine hydrochloride (TYR, $C_8H_{11}NO{\cdot}HCl$, >98%), 2-phenylethylamine hydrochloride (PHE, $C_8H_{11}N{\cdot}HCl$, >98%) and tryptamine hydrochloride (TRY, $C_{10}H_{12}N_2{\cdot}HCl$, >99%) for standard solutions preparation were supplied by Sigma-Aldrich (Milano, Italy). 1,7- diaminoheptane (98%) as the internal standard was supplied by Sigma-Aldrich (Milano, Italy). Hydrochloric acid (HCl, 37%) trichloroacetic acid (TCA, ≥99.0%), acetone (≥99,5%), sodium hydroxide anhydrous (NaOH, ≥98%), sodium carbonate anhydrous (Na_2CO_3, ≥99,5%), acetonitrile (CH_3CN, HPLC gradient grade, ≥99.9%), methanol (CH_3OH, HPLC gradient grade , ≥99.9%) and dansyl chloride ($C_{12}H_{12}ClNO_2S$, 98%) for extraction and derivatization were from Sigma-Aldrich (Milano, Italy).

Individual stock solutions of biogenic amines (BAs) were prepared by dissolving 10 mg of each compound in 10 mL of HCl 0,1 M (Merck Darmstadt, Germany) and were then stored in glass-stoppered bottles at 4 °C. Standard working solutions, at various concentrations, were prepared daily by appropriate dilution of different aliquots of the stock solutions with deionized water (<8MΩ cm resistivity) obtained from the Milli-Q SP Reagent Water System (Millipore, Bedford, MA, USA). Derivatization solution was prepared with dansyl chloride in acetone (10%).

2.4. Analysis of biogenic amines

BAs analytical procedure is based on a previously published method, slightly modified (Sirocchi et al., 2013). Each slice of chicken breast meat was ground with a blender, and then 5 g, in a centrifuge tube, were extracted with TCA 5% by Ultra-Turrax S 18 N-10G homogenizer (IKA-Werke Gmbh & Co., Germany). 0.2 mL of a 10 mg L^{-1} 1,7-diaminoheptane solution as internal standard, 0.3 mL of Na_2CO_3 saturated solution, and 50 μL of NaOH 2 N were added to 1 mL of isolated supernatant. For the derivatization step, 2 mL of dansyl chloride solution was used and samples were put at 45 °C for 45 min. Then, excess dansyl chloride was eliminated by adding 100 μL of NH_4OH 28%. SPE STRATA X 33 μ Cartridges, 200 mg/6 mL (Phenomenex, Bologna, Italy) were conditioned with 5 mL of CH_3CN followed by 5 mL of Milli-Q water. Samples were purified through the cartridge and eluted with 4 mL of CH_3CN. Samples were stored at 4 °C and filtered on a 0.45 μm PTFE filter (Supelco Bellefonte, PA, USA) before analysis. BAs separation was achieved using a Gemini C18 analytical column (250 × 4.6 mm I.D., particle size 4 μm) from Phenomenex (Torrance, CA, USA). The column was thermostated at 25 °C. The mobile phase for HPLC analysis was MilliQ water (A) and CH_3OH/CH_3CN 70:30 *v/v* solution (B), at a flow rate of 0.5 mL min^{-1}. The gradient program was: 0 min 60% B, 10 min 70% B, 20 min 90% B, 26 min 100% B, 29 min 100% B and 32 min 60% B until 40 min. The injection volume was 20 μL. High-performance liquid chromatography (HPLC) system was coupled with a Diode Array Detector (DAD). Peak responses were measured at 254 nm.

2.5. Analysis of volatile organic compounds

5 g of chicken breast meat was finely minced and homogenized for 30 *sec* in an analytical blender (Tube Mill Control, IKA-Werke GmbH & Co. KG, Germany). Then, 2 g of the sample was weighted in a 10 mL vial with a perforable septum and conditioned at 40 °C for 20 min. The SPME

fiber assembly was from Supelco (Bellefonte, PA, USA) and had a 50/30 μm divinylbenzene/carboxen/polydimethylsiloxane (DVB/CAR/PDMS) coating with 1 cm length stationary phase. Then, the fiber was exposed in the headspace of the vial containing the sample for 30 min. Volatile organic compounds (VOCs) were analyzed by GC–MS using a 6890 N Network GC System coupled to a 5973 Network Mass Selective Detector both from Agilent Technologies (Santa Clara, CA, USA). A capillary column coated with polyethylene glycol (60 m × 0.25 mm × 0.25 μm film thickness, DB-WAX, Agilent Technologies, Santa Clara, CA, USA) was used. The initial carrier gas (helium) flow rate was 1.2 mL min^{-1}. Injector temperature was 260 °C, splitless time was 4 min. The oven temperature was held at 35 °C for 4 min, then raised to 120 °C at 2.5 °C min^{-1} and then went up to 250 °C at 15 °C min^{-1} and held at this final temperature for 3.3 min, for a total run time of 50 min. Mass analysis was performed in scan mode in the range of 25–400 Da. The transfer line was maintained at 260 °C, ion source at 230 °C, and quadrupole at 150 °C. The SPME fiber was left exposed in the injector for 10 min to be cleaned after desorption and reactivated. Straight chain alkanes were used to calculate retention indices. Thus, the detected VOCs were identified by comparing their retention indices and mass spectra with those of standards from the US National Institute of Standards and Technology database (NIST-USA, http://webbook.nist.gov). An external standard (3-octanol in acetone, 0.5 mg mL^{-1}) was used to control the repeatability of the method. A proper aliquot of the standard solution (10 μL) was put in a 2 mL vial and analyzed in duplicate each day of analysis under the same conditions reported above.

2.6. Microbiological analysis

Chicken breast meat microbiota was monitored by determining total aerobic mesophiles, mesophilic lactic acid bacteria (LAB), β-glucosidase-positive *Escherichia coli*, *Enterobacteriaceae*, presumptive *Pseudomonas* spp., coagulase-positive staphylococci, anaerobic sulfite-reducing bacteria, *Clostridium perfringens*. The analyzed parameters followed the criterion of CeIRSA (2017) and the applied procedures were in accordance with the respective ISO guidelines. 10 g of chicken breast meat from each pack (PET and BP) were aseptically weighted inside sample bag (Whirl-Pak®, Seward, UK) and 90 mL of sterile 0.9% sodium chloride solution (NaCl) (Sigma-Aldrich, Co., St. Louis, USA) were added into sample bags and homogenized for 2 min by Stomacher. Then, 10-fold dilutions were prepared using a saline solution, and 0.1 mL of the corresponding dilutions was spread and inoculated into selective agar media. The aerobic mesophilic bacteria count was performed onto Plate Count Agar (PCA, Oxoid, Basinstoke, UK) under aerobic conditions at 30 °C for 72 h (ISO 4833). For the enumeration of mesophilic LAB, de Man, Rogosa, Sharpe agar (MRS Agar at pH 5.7, VWR, Leuven, Belgium) was used (ISO 15214:1998), while, Tryptone Bile X-glucuronide Agar (TBX, VWR) for the detection of β-glucosidase-positive *E. coli* was aerobically incubated for 18 h to 24 h at 44 °C (ISO 16649–2). The detection and enumeration of *Enterobacteriaceae*, were performed onto violet red bile glucose agar (VRBGA, VWR) inoculated with samples at 37 °C for 24 h (ISO 21528–2). The enumeration of presumptive *Pseudomonas* spp. was carried out by aerobically inoculating samples onto Pseudomonas Selective Agar (CFC, Liofilchem s.r.l., Roseto degli Abruzzi, Italy) at 25 °C for 44 h ± 4 h (ISO 13720:2010[E]). The presence of coagulase-positive staphylococci was checked through the aerobic inoculation onto the Baird-Parker agar medium (VWR) at 35–37 °C after 24 to 48 h of incubation (ISO 6888–1:1999 [E]). Sulfide-reducing bacteria were enumerated by using iron sulfite agar plates (Liofilchem) incubated under anaerobic conditions at 37 ± 1 °C for 48 h (ISO 15213:2003 [E]). *Cl. perfringens* count was on tryptose sulfite cycloserine (TSC) agar (VWR) under anaerobic conditions at 37 °C for 20 h ± 2 h (ISO 7937:2004 [E]).

2.7. pH measurement

The pH of chicken breast meat has been measured in triplicate, using a digital pH meter (Mettler Toledo, Columbus, UK) equipped with a probe for food through direct penetration in meat.

2.8. Sensory analyses

Sensorial analyses were conducted on raw chicken breast meat aspect (slime), odor, color, texture (elasticity), overall acceptability using a three-point hedonic scale, ranging from extremely dislike/reject (Score: 1) to extremely like/satisfy (Score: 3) on the same time points of the analysis (Huang et al., 2020) (Table 1S). The sensory panel was composed of 10 panelists from the laboratory, they had been trained before performing tests on selected samples in order to familiarize chicken breast meat sensorial attributes and terminology. Each sample was assigned a code; the panelists gave scores based on the coded samples.

2.9. Statistical analysis

Significant differences between the storage in the two different packagings (BP and PET) and between the different times of analysis were evaluated by one-way analysis of variance (ANOVA). Differences with $p < 0.05$ were considered statistically significant. Data elaboration was carried out using the PAST software package (Hammer, Harper & Ryan, 2001). Each experiment was performed in triplicate.

3. Results and discussion

3.1. Analysis of biogenic amines

The analytical method was previously validated according to the criteria of European Regulations for quantitative methods of confirmation. The HPLC-DAD chromatogram of BAs mixture at 25 mg L^{-1} and 1,7-diaminoheptane, used as internal standard, is shown in Fig. 2S. The calibration curve of each BA was calculated using the response factor, which is the ratio between the BA peak area and the internal standard peak area. All calibration curves of BAs showed good linearity ($r^2 >$ 0.9956). Under these HPLC conditions, each BA and internal standard are clearly resolved, indicating that this method can be used for the quantitative determination of BAs in food samples.

Fig. 1 reports the Total content of BAs (A), the Biogenic Amine Index (B), and the spermidine/spermine ratio (C) related to chicken breast meat wrapped in BP and PET packaging during the shelf life study. Samples were prepared according to the procedure described in section 2.4; each sample was analyzed in triplicate.

Several studies reported biogenic amines as indicators of meat freshness. Concentrations of some biogenic amines such as tyramine, putrescine, and cadaverine, normally increase during storage of meat and meat products, whereas spermidine and spermine decrease or remain constant (Önal, Tekkeli, & Önal, 2013; Wójcik, Łukasiewicz, & Puppel, 2021; Yusoff, Jaffri, & Azhari, 2021). The Total content of BAs showed a similar trend of growth both for BP and PET packaged meat, with two significant differences at day 3 and day 10 in favor of BP and PET, respectively (Fig. 1A). The Biogenic Amine Index (BAI) (Douny et al, 2019) increased rapidly from day 6 to day 10 in the meat wrapped both in PET and BP packs. PET packaged meat values shifted from 65 mg Kg^{-1} at day 6 to 159 mg Kg^{-1} at day 10, while meat wrapped in BP from 61 mg Kg^{-1} to 245 mg Kg^{-1} in the same range of time (Fig. 1B), without statistically significant differences.

Concerning the ratio between spermidine (SPD) and spermine (SPM) that is considered one of the most important indexes for evaluating the quality of chicken meat because is independent of the type of flora (Sirocchi et., 2013), the values are quite constant for both packaged meat (BP and PET) during the shelf life study (Fig. 1 C). No statistically

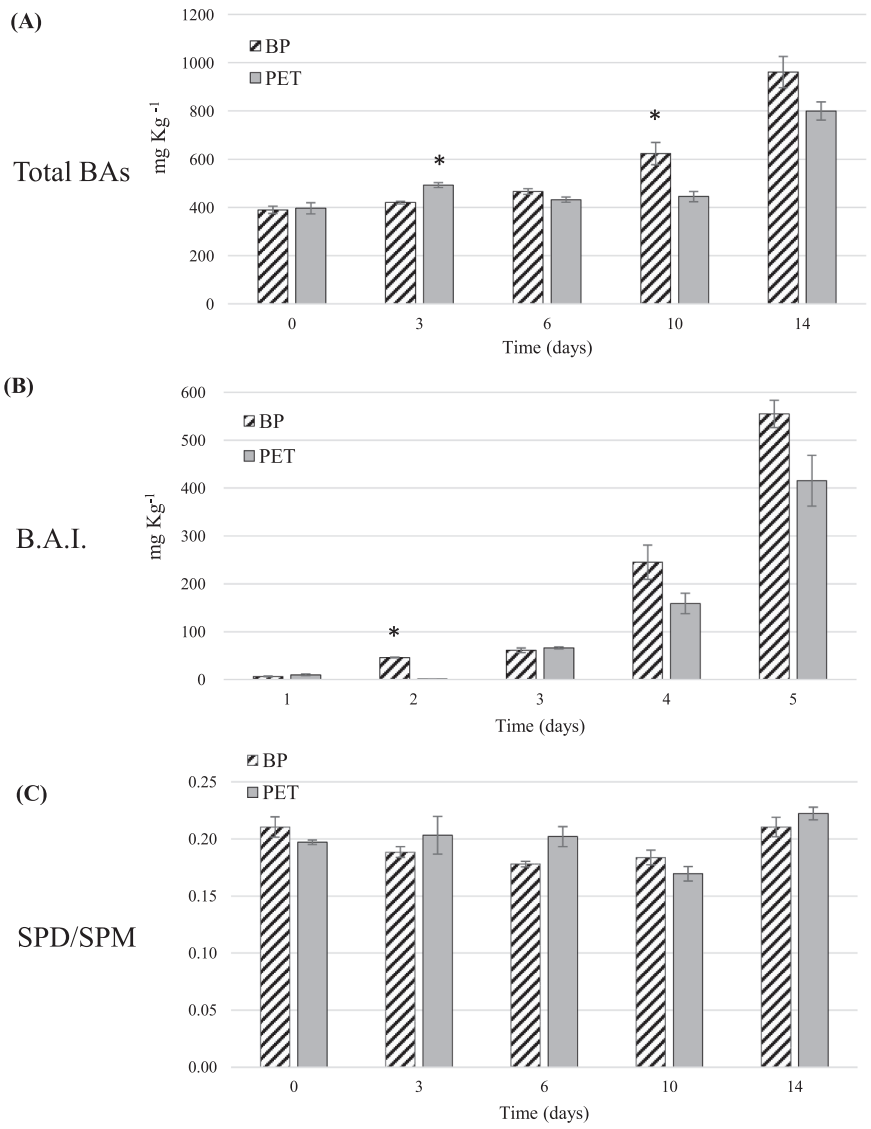

Fig. 1. Comparison (±standard deviation) of the sum of average concentrations of analysed BAs (A), Biogenic Amine Index (B) and Spermidine/spermine ratio (C) of chicken breast meat in the two types of packaging (BP and PET) during the storage period. Significant differences ($p < 0.05$) between the two packaging in each day are indicated by the asterisk.

significant differences have been recorded for SPD/SPM between the two different packagings. Similar results of SPD/SPM ratios were reported for chicken (Silva & Gloria, 2002), fish (Biji, Ravishankar, Venkateswarlu, Mohan, & Srinivasa Gopal, 2016), and pork (Ngapo & Vachon, 2017) food matrices. These results are in agreement with those published by Silva and Glòria (2002) that report the SPM prevalence over SPD level during the 14-days storage period, assessing that SPM decreases because microorganisms take up this polyamine as a nitrogen source.

Finally, the comparison between the BAs level of chicken meat wrapped in BP and PET packaging shows a similar trend in the concentrations of Total BAs, BAI, and the ratio SPD/SPM.

3.2. Analysis of volatile organic compounds (VOCs)

The formation and release of VOCs by chicken breast meat in two different packagings (BP and PET) over a 14-days storage period was assessed by HS-SPME-GC–MS. VOCs that are in part spoilage by-products were monitored on different days: at time zero and after 3, 6, 9, and 14 days.

A number of 18 VOCs were identified in the chicken breast meat packed in PET and BP and they are listed in Table 1. These compounds were alcohols, phenols, ketones, acids, and sulfur-containing compounds. Most of them are reported as common VOCs detected during fresh meat storage (Casaburi, Piombino, Nychas, Villani & Ercolini, 2015). Some of these compounds (e.g. 3-methyl butanol, 1-pentanol, 3-hydroxy-butanone, and acetic acid) increased during the storage period in both PET and BP packaging, and some VOCs (e.g. 1-octanol, 1-octen-3-ol) could be found only at the end of the storage period (after 9 or 14 days). A selection of identified compounds is plotted in Fig. 2.

Alcohols can be produced by specific microorganisms during the storage of fresh meat, such as *Pseudomonas* and *Carnobacteria* (Casaburi et al. 2015). 1-Octen-3-ol and 3-methyl-1-butanol are the most frequently detected alcohols in raw meat (Casaburi et al., 2015). 1-Octen-3-ol mainly derives from the oxidation of linoleic and linolenic acids (Curioni & Bosset, 2002) and is known to contribute significantly to the aroma of meat (Casaburi et al., 2015). After day 3, it was detected in PET packaging and after day 6 in BP packaging, showing an increase in both packaging during the storage period. At day 14, 1-octen-3-ol is the only VOC that resulted to be significantly more abundant in BP than

Table 1
Volatile compounds detected by HS-SPME-GC–MS during the storage of chicken breast meat in BP and PET packaging, their experimental linear retention indices (LRI) on a polyethyleneglycol coated column, their odor attribute, their abundances in terms of peak areas and % relative standard deviation (RSD, $n = 2$). Significant differences ($p < 0.05$) between the two packaging in each day are indicated by the asterisk. Significant differences ($p < 0.05$) between the different days for each of the two packaging are indicated by different letters in the same row.

Compound	Odor attribute	LRI[1](exptl)	LRI[2](lit)		Day of storage										SI[3](%)
					0		3		6		10		14		
					Area	RSD%	Area	RSD%	Area	RSD%	Area	RSD%	Area	RSD%	
	Alcohols and phenols														
Isopropyl alcohol	Musty	929	926	BP	5,04E + 06^{a} *	8.0	4,73E + 06^{a} *	4.3	2,14E + 06^{b} *	7.8	2,38E + 06^{b} *	0.3	7,22E + 06^{c} *	3.0	80
				PET	1,93E + 07^{a}	4.5	2,07E + 07^{a}	1.6	6,47E + 06^{b}	8.9	1,48E + 07^{c}	14.8	1,18E + 07^{c}	4.3	
1-Propanol	Musty	1038	1036	BP	2,86E + 07^{a} *	8.5	5,13E + 07^{b} *	0.7	1,49E + 07^{c} *	10.1	1,20E + 07^{c} *	11.0	4,25E + 07^{d} *	2.3	86
				PET	1,24E + 08^{a}	1.1	1,27E + 08^{a}	0.8	5,96E + 07^{b,d}	11.9	9,04E + 07^{c,d}	10.5	8,08E + 07^{d}	2.1	
3-Methylbutanol	Roasted	1213	1208	BP	nd	nd	nd	nd	nd	nd	4,70E + 05^{a}	27.6	2,08E + 06^{b}	17.9	80
				PET	nd	nd	nd	nd	nd	nd	8,46E + 05	29.3	1,63E + 06	6.4	
1-Pentanol	Fusel	1254	1252	BP	1,08E + 05^{a}	10.5	1,57E + 05^{a} *	1.7	6,64E + 05^{b}	9.7	8,68E + 05^{c}	1.6	9,56E + 05^{c}	5.2	88
				PET	1,58E + 05^{a}	12.1	6,97E + 05^{b}	18.3	1,02E + 06^{b}	11.4	7,72E + 05^{b}	14.2	1,03E + 06^{b}	6.6	
1-Hexanol	Fruity	1356	1354	BP	nd	nd	nd	nd	2,72E + 05^{a}	2.0	1,77E + 05^{b}	2.0	2,92E + 05^{a}	11.4	82
				PET	nd	nd	3,33E + 05	11.1	2,61E + 05	0.9	2,97E + 05	22.3	3,66E + 05	14.7	
1-Octen-3-ol	Earthy	1451	1449	BP	nd	nd	nd	nd	1,92E + 05^{a}	20.1	3,63E + 05^{b}	5.4	7,66E + 05^{c} *	2.1	83
				PET	nd	nd	1,57E + 05^{a}	26.0	3,25E + 05^{a,b}	17.9	4,76E + 05^{b}	15.9	5,27E + 05^{b}	14.7	
1-Octanol	Waxy	1566	1565	BP	nd	nd	nd	nd	nd	nd	nd	nd	3,15E + 05*	33.3	85
				PET	nd	nd	nd	nd	nd	nd	nd	nd	9,48E + 05	7.8	
Phenol	Sweet	1998	1996	BP	1.6E + 05	10.4	nd	nd	1,29E + 05	2.1	1,08E + 05	16.8	1,30E + 05 *	22.3	83
				PET	1,23E + 05^{a}	28.7	2,41E + 05^{a}	21.8	nd	nd	2,82E + 05^{a}	30.9	1,02E + 06^{b}	2.5	
	Ketones														
2-Butanone	Fruity	892	894	BP	3,76E + 05^{a}	22.7	2,82E + 05^{a}	13.8	8,70E + 05^{b} *	3.7	7,89E + 05^{b} *	0.5	2,99E + 05^{a}	18.8	82
				PET	nd	nd	2.75E + 05^{a}	5.1	3,64E + 05^{a,b}	8.4	3,96E + 05^{b}	11.9	1,31E + 05^{c}	4.4	
2,3-Butanedione	Buttery	966	970	BP	nd	nd	7,87E + 05^{a}	25.3	3,25E + 05^{b}	1.5	6,64E + 05^{a,b}	5.1	1,54E + 06^{c}	4.3	81
				PET	3.75E + 05^{a}	30.1	1,45E + 06^{b}	21.6	2,70E + 05^{a,c}	30.2	1,04E + 06^{a,b}	23.4	1,71E + 06^{b,d}	7.6	
3-Hydroxy-2-butanone	Creamy	1280	1278	BP	nd	nd	nd	nd	7,88E + 05^{a}	1.2	1,80E + 06^{b} *	6.7	4,96E + 06^{c} *	3.2	84
				PET	nd	nd	nd	nd	nd	nd	1,11E + 06^{a}	6.7	6,41E + 06^{b}	3.8	
	Acids														
Acetic acid	Vinegar	1446	1453	BP	1,84E + 05^{a}	25.3	1,52E + 05^{a}	4.7	4,02E + 05^{a,b}	23.5	2,64E + 05^{a}	14.6	7,36E + 05^{b}	23.3	90
				PET	nd	nd	1,66E + 05^{a}	7.0	2,82E + 05^{a,b}	6.6	3,08E + 05^{b}	17.1	1,12E + 06^{c}	0.8	
Propanoic acid	Pungent	1539	1538	BP	nd	nd	7,68E + 05^{a} *	6.3	6,96E + 04^{b}	23.8	nd	nd	8,75E + 04^{b} *	35.2	89
				PET	nd	nd	9,55E + 05^{a}	2.2	6,33E + 04^{b}	13.3	2,98E + 05^{c}	5.6	2,22E + 05^{d}	3.6	
Isovaleric acid	Cheesy	1670	1670	BP	nd	nd	nd	nd	6,22E + 05	28.0	6,43E + 05 *	12.6	2,41E + 05 *	16.8	83
				PET	nd	nd	nd	nd	1,41E + 05^{a}	4.7	4,00E + 06^{b}	8.5	9,29E + 05	4.0	
Hexanoic acid	Sour	1843	1839	BP	1,62E + 05^{a,b}	4.5	1,49E + 05^{a,b}	2.3	2,84E + 05^{a}	12.5	1,33E + 05^{b}	12.8	1,79E + 05^{a,b}	34.3	80
				PET	1,55E + 05^{a}	16.7	nd	nd	2,12E + 05^{a,b}	1.3	2,63E + 05^{a,b}	22.3	3,32E + 05^{b}	11.6	
Nonanoic acid	Rancid	2161	2168	BP	2,25E + 05	28.3	1,86E + 05	30.1	3,32E + 05	21.9	2,19E + 05	14.2	2.74E + 05	21.9	81
				PET	2,19E + 05	31.1	2.25E + 05	12.8	2,85E + 05	9.3	2,06E + 05	17.8	2,76E + 05	18.2	
	Sulfur containing compounds														
Carbon disulfide	Ether-like	714	710	BP	2.27E + 05^{a}	31.8	2,05E + 05^{a}	8.9	2,00E + 06^{b}	33.0	8.57E + 05^{a,b}	16.1	2,05E + 05^{a}	28.9	94
				PET	1,15E + 06^{a,b}	11.0	1,95E + 05^{a}	1.7	2,14E + 06^{b}	38.9	7,66E + 05^{a,b}	22.6	nd	nd	
Dimethyl sulfone	Cabbage-like	1904	1911	BP	4,11E + 05^{a} *	8.6	9,78E + 04^{b}	14.2	1,16E + 05^{b,c}	39.3	1,72E + 05^{b,c}	11.7	2,40E + 05^{c}	13.6	96
				PET	5,38E + 04^{a}	7.1	1,14E + 05^{a}	26.7	3,68E + 05^{b}	27.4	8,17E + 04^{a}	33.0	2,42E + 05^{a,b}	0.6	

[1] Experimental linear retention index;
[2] Linear retention indices reported in literature;
[3] Similarity index.
nd: not detected (peak area value below 5E + 04).

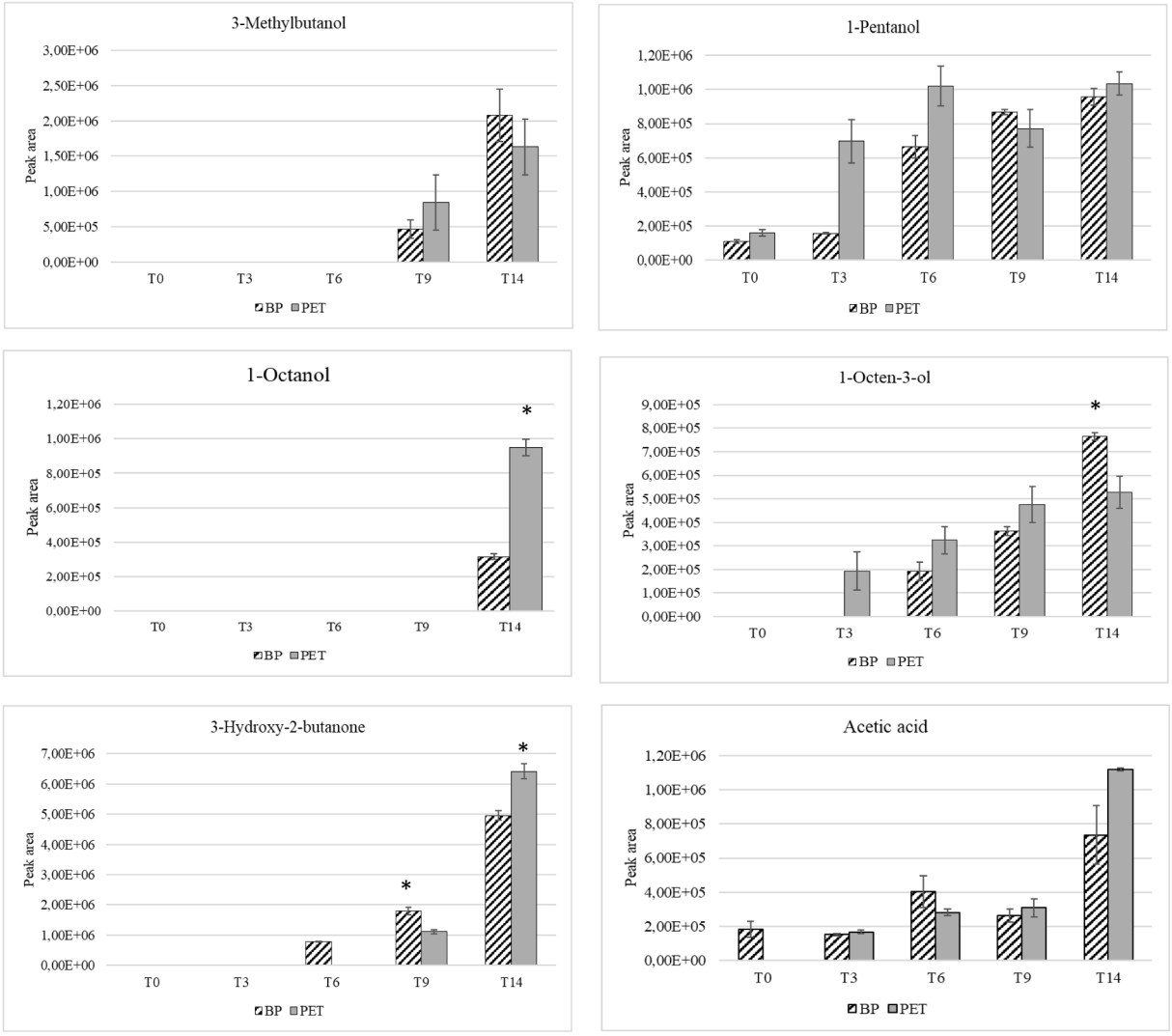

Fig. 2. Comparison of the average peak areas (±standard deviation) of selected VOCs in chicken breast meat in the two types of packaging (BP and PET) during the storage period. Significant differences ($p < 0.05$) between the two packaging in each day are indicated by the asterisk.

in PET packaging. 3-Methyl-1-butanol is known to derive from the proteolytic pathway of leucine and it has been used as a chemical marker for chicken meat spoilage in previous studies (Casaburi et al., 2015; Alexandrakis, Brunton, Downey & Scannell, 2011). In this study, it was detected at day 9 in both packaging, indicating that it could be considered as a marker of the latter stages of the spoilage process, as 1-octanol, that was detected only after 14 days of storage in both packaging. 1-Pentanol was present in both the fresh and aged samples, with a higher presence in the latter for both packagings. Both 1-pentanol and 1-octanol are well-known lipid oxidation products (Shahidi, 1994).

Ketones are known to derive from fatty acids oxidation and have been used as meat-aging indicators also in previous studies (Estévez, Morcuende, Ventanas & Cava, 2003; Zareian et al., 2018; Klein, Maurer, Herbert, Kreyenschmidt & Kaul, 2017). Ketones detected in this study include 2-butanone, 2,3-butanedione (diacetyl) and 3-hydroxy-2-butanone (acetoin). Acetoin a was detected at day 6 in BP and at day 9 in PET packaging, showing a significant increase in 14-day old samples. In particular, on day 14 acetoin quantity was significantly higher in PET as compared to BP packaging. Short and medium-chain free fatty acids detected in the samples are acetic, propionic, isovaleric, hexanoic, and nonanoic acids. Typically, LAB are the major responsible for the production of volatile fatty acids during meat storage (Casaburi et al., 2015). Acetic acid, the most abundant short-chain fatty acid detected, was found in both fresh and aged samples, showing a significant increase for both packagings after 14 days of storage, but with no significant differences between the two packagings. In general, the development of VOCs associated with meat spoilage was not significantly more pronounced in the BP packaging, thus contributing to demonstrate BP packaging suitability for meat chilled storage.

3.3. Microbiological analysis

Data of each analyzed microbial group of both PET and BP samples are shown in Fig. 3. The counts of β-glucosidase-positive *E. coli,* anaerobic sulfite-reducing bacteria, *Cl. perfringens* were under the detection limit throughout the study period. The bacterial counts of PET and BP samples increased during the storage period, with no significant difference found between the two types of packaging materials. Both samples showed the initial value of total aerobic mesophile around 4.2 log CFU g^{-1} which represented the analyzed meat with good quality (Dawson et al., 1995; Latou et al., 2014). As the criterion of FCD (2009) suggested that the acceptable limit of total aerobic mesophiles is within 6 log CFU g^{-1} to 8 log CFU g^{-1}. As Fig. 3A demonstrates, BP and PET samples reached the limit approximately at 12 days and 13 days of chill storage, respectively. Lactic acid bacteria (LAB) are facultative anaerobic bacteria that can grow with the presence of oxygen or not, and some species

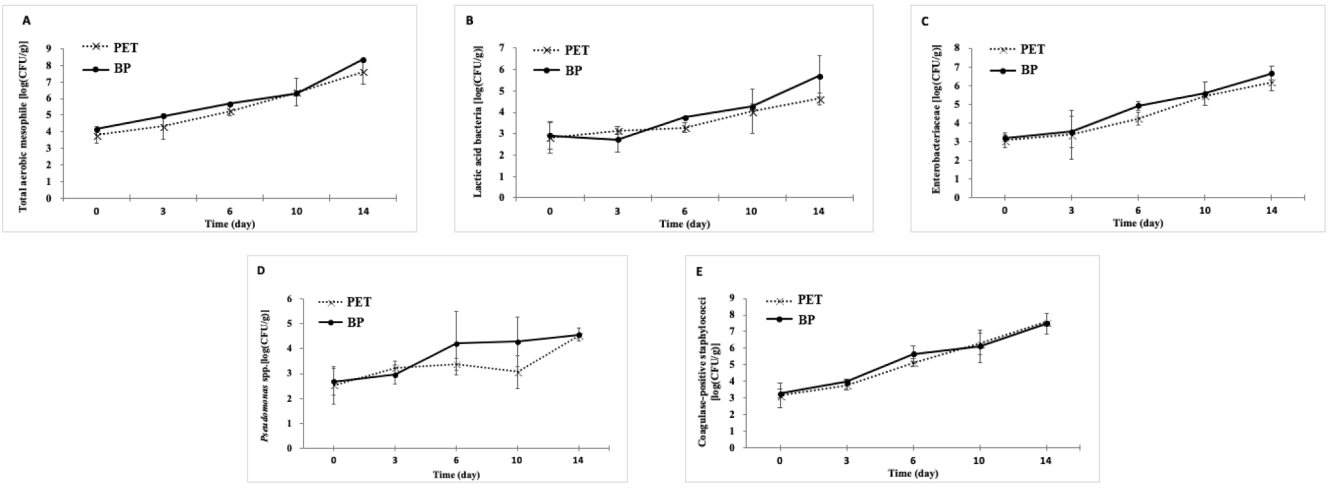

Fig. 3. Bacterial counts of total aerobic mesophile (A), mesophilic lactic acid bacteria (B), Enterobacteriaceae (C), presumptive *Pseudomonas* spp.(D), coagulase-positive staphylococci (E) during 0, 3, 6, 10, 14 days storage at 4 °C, detected in meat samples inside PET and BP packaging. Error bars represented standard deviations of the mean value.

of LAB constitute part of the natural microflora and some were found to be the main microorganisms related to meat spoilage (Jay et al., 2005; Casaburi et al., 2015). In both samples, the level of LAB increased during the study period which is corresponding to the decreased pH.

The amount of Enterobacteriaceae is a good indicator of the general hygiene condition of the fresh poultry meat and temperature abuse during storage (Zeitoun et al., 1994). The modified air together with chill storage conditions slows down the proliferation of Enterobacteriaceae. The count was slightly above 3 log CFU g^{-1}at the starting point and it maintained for the first three days of storage, then increased about up to 6 log CFU g^{-1}. *Pseudomonas* spp. have been identified as the main spoilage microorganisms of chilled poultry meat (Wickramasinghe et al., 2019). Although the final count of *Pseudomonas* spp. was the same in both samples, PET samples showed a lower amount of this bacteria group than BP samples during day 3 to day 14. Some studies demonstrated that the *Pseudomonas* spp. were resistant to high levels of oxygen, while sensitive to high concentrations of carbon dioxide (Meredith et al., 2014). In the study performed by Chmiel et al. (2018), the count of *Pseudomonas* increased during the study period and with a significantly higher amount in air condition compared to MAP with 80% O_2 during storage. Coagulase-positive staphylococci (CPS) have been reported to the most common species related to foodborne illness (Do Carmo et al., 2004). Fig. 3E shows that CPS of both samples showed a similar increasing trend with 4 log CFU g^{-1} increase during the 14 days storage at 4 °C. Finally, concerning the microbiological evaluation, no significant differences have been reported between BP and PET packaging materials in the preservation of chicken meat.

3.4. pH measurement

The pH values of both samples remained during the first three days of storage and slightly decreased during the following period (Fig. 4). For meat stored in BP packaging system, it started with a value of 6.5, following a slight decrement at day 3 to 6.3 reaching 6.0 at the end. PET samples initial value was maintained during the first three days and it also decreased to 6 at day 14. In general, there were small variations found between the two packaging systems throughout study period and this effect could be attributed to the strong buffering capacity of chicken fat.

3.5. Sensory evaluation

The scores of meat sensorial attributes, aspect, color, odor, elasticity, and overall acceptability, were illustrated in Fig. 5 and Table 1S. In

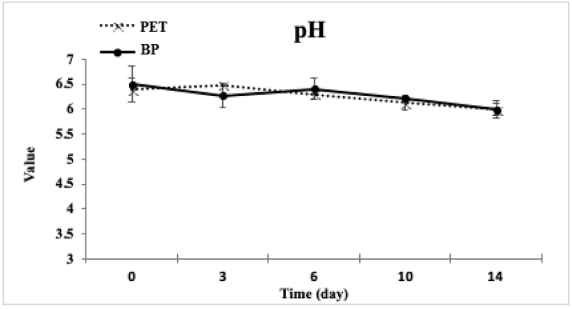

Fig. 4. pH values of raw chicken breast meat stored in PET and BP packaging.

general, attributes scores of both samples showed a decreasing trend and BP samples obtained higher scores than PET samples for meat aspect, color, overall acceptability on days 3, 6, and 10. However, on the last day of evaluation, panelists indicated PET samples were generally better than BP samples for all examined attributes. As for the other sensorial attributes, such as odor and elasticity (Fig. 5B and 5D), both samples exhibited similar results for the first 10 days of storage, with higher scores obtained from PET samples at day 14. According to Chmiel et al. (2018), chicken breast meat wrapped in PET was acceptable up to 9 days under MAP (75% O_2 and 25% CO_2) in the cooling room.

3.6. Discussion

In this research, the ability of a new biopackaging (BP) to preserve the quality of organic chicken meat in comparison to a classic polyethylene-terephthalate packaging (PET) has been evaluated. Chemical and microbiological markers of chicken meat (BAs, VOCs, selected microorganisms), pH, and sensorial parameters were monitored for 14 days in both packaged meat (BP and PET). The studied indices of BAs, i.e. Total BAs, BAI, and SPD/SPM ratio during the shelf life of meat showed a similar trend for both packs, and similar results have been obtained for the analysis of VOCs. The counts of total aerobic mesophile, mesophilic lactic acid bacteria, Enterobacteriaceae, presumptive *Pseudomonas* spp., and coagulase-positive staphylococci were not significantly different in the meat wrapped in BP and PET; moreover, the pH value was maintained during 14 days at chilled temperatures with slightly decrement. Concerning the sensorial evaluation, no significant differences were observed between meat BP and PET. Therefore, this new biopackaging showed similar performances in fresh chicken

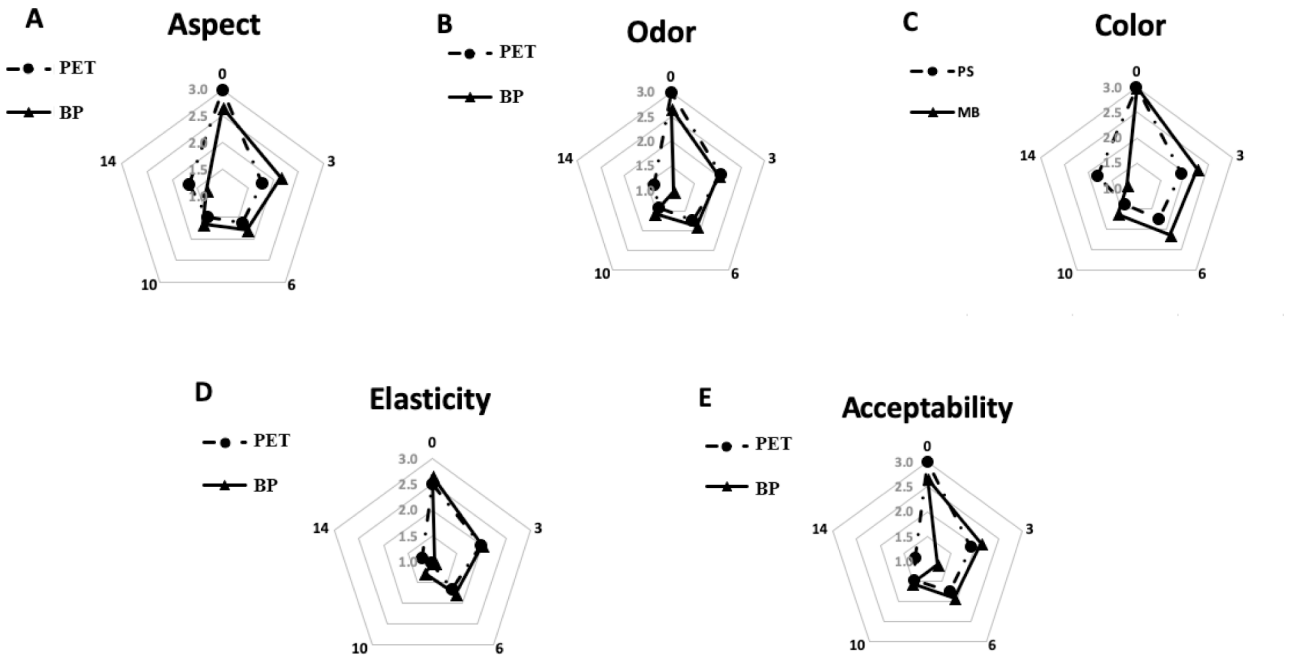

Fig. 5. Sensory evaluation of PET and BP samples at 0, 3, 6, 10, 14 days stored at 4 °C. Organoleptic descriptors of meat are reported in Table 1S (evaluation score from 1 to 3): A - aspect. B - odor. C - color. D - elasticity. E - acceptability.

conservation compared to classic packaging.

The assessment of the performances of biodegradable packaging in fresh meat preservation has been reported in few studies (Cheng et al., 2021). Compared to the literature, Moreno et al. (2018), reported that the storage of chicken breast fillets in oxidized starch biopackaging enhanced the microbiological shelf life of chicken but promoted lipid oxidation affecting the meat pH and color.

The BP performances could be further improved through the incorporation of bioactive additives with antioxidant or antimicrobial activities (Cheng et al., 2019; Baek, Kim, & Song, 2019). Indeed, Hassan et al. (2019) developed a new starch-based biopackaging incorporated with rosehip extract, which limited the lipid oxidation in chicken breasts during storage.

The proposed material is a result of a customized multi-layers structure that has been developed by exploiting the different properties of Novamont's bio-polymers, such as:

- HDT properties (Heat Deflection Temperature) that allowed to overcome the main problems related to storage temperarure of trays before use (i.e. wharehous)
- Barriers properties that enabled the final structure to be used for different protective packaging with controlled atmosphere for all meats and fresh food.

Thanks to the compostability of different layers all the packaging can be completely organic recycled (differently from the not reclable traditional multi-layers structures).

4. Conclusions

This study showed that the new biopackaging (BP) is able to preserve chicken meat as a common plastic material (PET). Indeed, chemical, microbiological, and sensorial evaluations of chicken during storage revealed no statistically significant differences among the tested packaging, with the great advantage that the BP is completely biodegradable, compostable, and sustainable for the environment thanks to the complete organic recyclability in organic waste treatment plants (according to European standard EN13432). Further developments will consist to assess the preservation of other foods in the same packaging to promote a circular economy that can be only reached with the use of biodegradable and low environmental impact materials.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

We are grateful to Marche Region through the "Programma di Sviluppo Rurale (PSR) 2014/2020 Misura 16.1" (ID 29057) for financially supporting the project.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.foodchem.2021.131134.

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